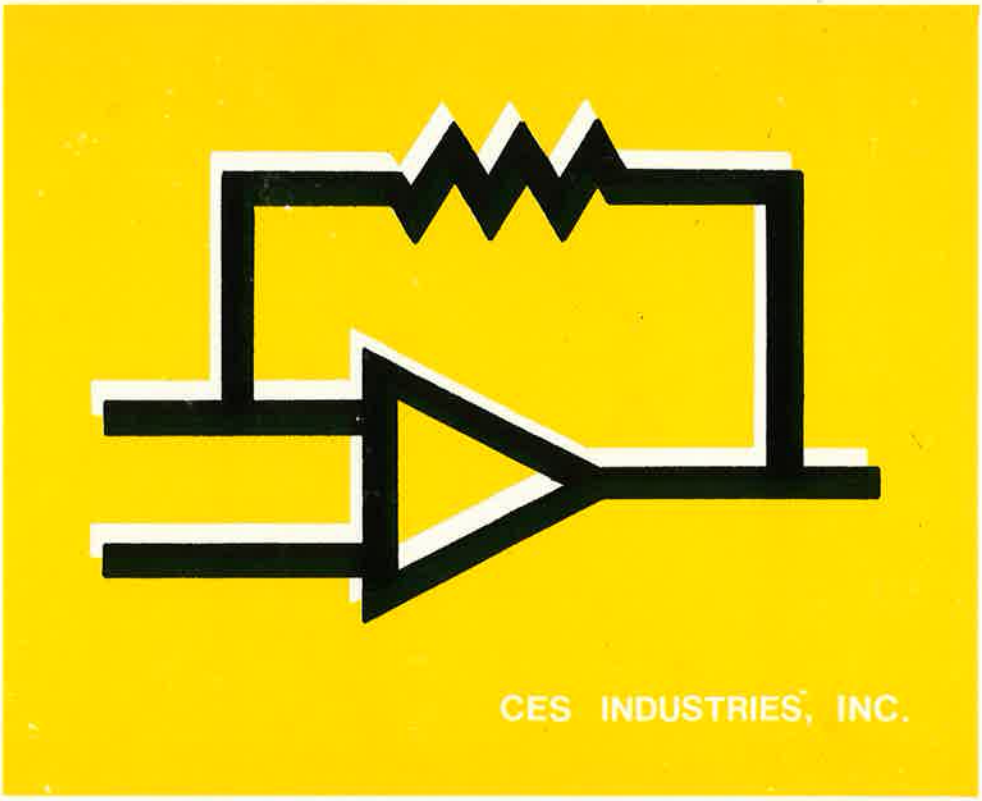
Ed-Lab

EXPERIMENT MANUAL

OPERATIONAL AMPLIFIERS BOOK IV

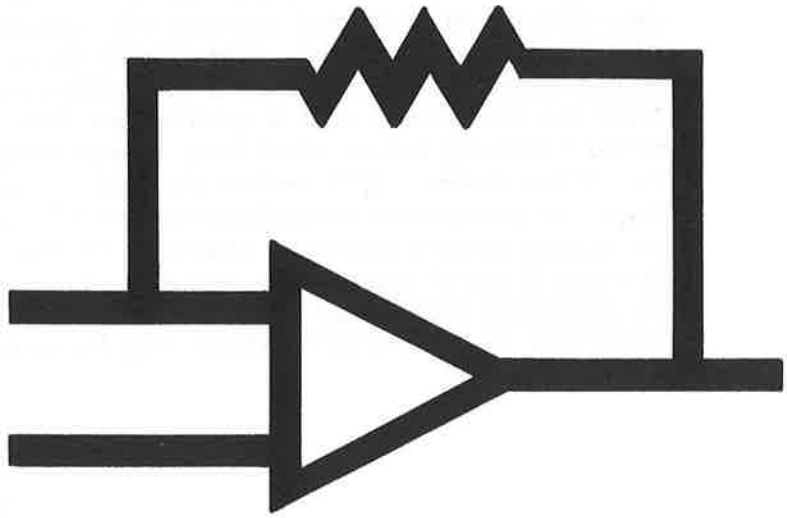


CES INDUSTRIES, INC.

Ed-Lab

EXPERIMENT MANUAL

OPERATIONAL AMPLIFIERS BOOK IV



CES INDUSTRIES, INC.

Name _____

Class _____

School _____

Ed-Lab

EXPERIMENT MANUAL

OPERATIONAL AMPLIFIERS

UNIT NO. 9

Copyright © 1981 CES INDUSTRIES, INC.

All rights reserved. No part of this book may be duplicated or reproduced in any form without the specific written permission of CES Industries, Inc. The use of this manual and the experiments described is restricted to performance with CES Ed-Lab training equipment and is prohibited from being used with any other training aid or electronic components or for other educational purposes. CES makes no representation that the circuits, logic, or programs described herein will not infringe on existing or future patent rights. There is furthermore no implication in the granting of licenses to make, sell, or use any circuits, logic, or programs described herein. This does not restrict use of any materials or data sheets which may be available from other sources.

ISBN 0-86711-016-3
Printed in United States of America

CES INDUSTRIES, INC.
Educational Products Division
130 Central Avenue
Farmingdale, New York 11735
(516) 293-1420

PREFACE

During the past decade, the advancements in electronic components, including new types of transistors, integrated circuits and electro-optical devices, have lead to increased applications of electronics in computation, process and industrial controls, digital control and data processing, communications, medical diagnosis and treatment, automobile controls, guidance and navigation, and in the entertainment and sports industries as well.

One common requirement for students, in any aspect of the field of electricity-electronics, is for a good foundation in what all refer to as the Basics. This covers not only D.C. and A.C. Circuits and measurements of current, voltage, resistance, power, and Test Instruments, but must also include an understanding of measurements and tolerances and concepts of gain, loading, accuracy, signal flow, biasing, operating range, inputs, outputs, response, and other such factors. One should be able to determine when something is working or not working, and whether it is working "close enough" to the requirements to be considered good. An exposure to a wide variety of circuit configurations and applications will enable the student to recognize and be familiar with equipment in all fields.

The Ed-Lab Program has been developed to provide a truly practical experiment and experience exposure with fully coordinated hardware and software. The experiments each demonstrate single concepts and are straight-forward in approach. The circuits and theory are briefly explained. But there is no such thing as a "cookbook" with fixed answers. Measured values and tolerances are always different from the theoretical results and the student must determine when his results verify the theory. The "satisfaction of doing" and obtaining results leads to knowing and understanding. The mathematics is held to a minimum in the laboratory experiments. The required math is already done and the laboratory tests must verify or measure performance, accuracy, range and so on.

The Ed-Lab approach uses permanently mounted components with interconnections made by full-sized banana plugs so that there is no requirment to keep track of parts and no bad connections. Experience with actual components is essential and is provided with plug-in breadboard and prototype circuit cards where the student handles the parts, reads the circuit schematics and component specification sheets, interconnects the components and then "debugs", tests, and reports on the results.

Built-in power supplies provide positive and negative voltages, and the current is limited to prevent burning-out the supply or even any of the components. The overall design and concept results in what we believe is outstanding for full individual experimentation at the student's own rate and level and for demonstration as well.

We hope that this program will provide you with much knowledge, experience enjoyment, enthusiasm and continuing rewards for your efforts.

Norman Nesenoff, President
CES INDUSTRIES, INC.

Safety is good common sense. The Ed-Lab equipment is designed with all current limited and voltage limited Power Supplies so that there is no danger to the student when touching any wires and no danger of burning-out any of the electronic components.

DO NOT USE AN EXTERNAL POWER SUPPLY WITH THE ED-LAB.

While working in the laboratory, the student is exposed to many different types of equipment, power tools, soldering irons, test equipment, drills, rotating machinery, and so on. The 120 volt power socket can cause a shock, and the shock can result in your jumping or falling. Care should be exercised while working on any equipment including automobiles, television sets, carpentry tools, as well as electricity and electronics.

Do not get involved in any "horsing-around" or in practical jokes. Don't throw anything in the lab. Don't drop the equipment off the bench or on your foot. Don't burn the line cord with a soldering iron. If you remove the Ed-Lab front panel, don't touch the 120 volt line-cord connections in the rear while the plug is still connected to the socket.

If an accident occurs, notify your instructor, shut off all power, and administer first aid as necessary. Your instructor should review with you the safetv requirements in your laboratory.

Ed-Lab

FIRST AID for ELECTRICAL SHOCK

If you observe an accident involving electrical shock,
DON'T JUST STAND THERE - DO SOMETHING!

RESCUE OF SHOCK VICTIM

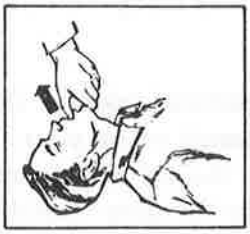
The victim of electrical shock is dependent upon you to give him prompt first aid. Observe these precautions:

1. Shut off the high voltage.
2. If the high voltage cannot be turned off without delay, free the victim from the live conductor. REMEMBER:
   a. Protect yourself with dry insulating material.
   b. Use a dry board, your belt, dry clothing, or other non-conducting material to free the victim. When possible PUSH - DO NOT PULL the victim free of the high voltage source.
   c. DO NOT touch the victim with your bare hands until the high voltage circuit is broken.

FIRST AID

The two most likely results of electrical shock are: bodily injury from falling, and cessation of breathing. While doctors and pulmotors are being sent for, DO THESE THINGS:

1. Control bleeding by use of pressure or a tourniquet.
2. Begin IMMEDIATELY to use artificial respiration if the victim is not breathing or is breathing poorly:
   a. Turn the victim on his back.
   b. Clean the mouth, nose, and throat. (If they appear clean, start artificial respiration immediately. If foreign matter is present, wipe it away quickly with a cloth or your fingers).



   c. Place the victim's head in the "sword-swallowing" position. (Place the head as far back as possible so that the front of the neck is stretched).
   d. Hold the lower jaw up. (Insert your thumb between the victim's teeth at the midline - pull the lower jaw forcefully outward so that the lower teeth are further forward than the upper teeth. Hold the jaw in this position as long as the victim is unconscious).
   e. Close the victim's nose. (Compress the nose between your thumb and forefinger).
   f. Blow air into the victim's lungs. (Take a deep breath and cover the victim's open mouth with your open mouth, making the contact air-tight. Blow until the chest rises. If the chest does not rise when you blow, improve the position of the victim's air passageway, and blow more forcefully. Blow <u>forcefully</u> into <u>adults</u>, and <u>gently</u> into <u>children</u>.
   g. Let air out of the victim's lungs. (After the chest rises, quickly separate lip contact with the victim allowing him to exhale).
   h. Repeat steps f. and g. at the rate of 12 to 20 times per minute. Continue rhythmically without interruption until the victim starts breathing or is pronounced dead. (A smooth rhythm is desirable, but split-second timing is not essential).

DON'T JUST STAND THERE - DO SOMETHING!

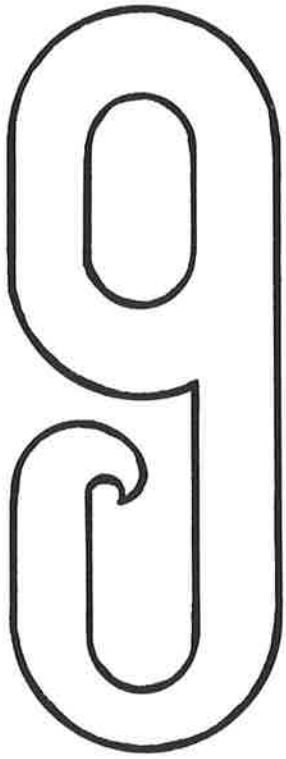
TABLE OF CONTENTS

1. Discrete Op-Amp
2. I.C. Op-Amp
3. External Op-Amp
4. Voltage Follower
5. A.C. Voltage Follower
6. Inverting Amplifier
7. Non-Inverting Amplifier
8. Summing Amplifier
9. Offset Null
10. Subtractor (Differential Input)
11. Integrator
12. Log Amplifier
13. Log Amplifier with Gain
14. Differentiator
15. Ultra-Linear Rectifier
16. Astable Operation
17. Bistable Operation
18. Voltage to Current Converter
19. Current Amplifier
20. Comparator
21. Schmitt Trigger Comparator
22. Instrumentation - Bridge Amplifier
23. Wein Bridge Oscillator
24. Gain - Bandwidth
25. Active Filters

Ed-Lab

EXPERIMENT MANUAL

OPERATIONAL AMPLIFIERS



UNIT NO.

CES INDUSTRIES, INC.

Ed-Lab	DISCRETE OP-AMP	EXP. NO. 1 Page No. 1

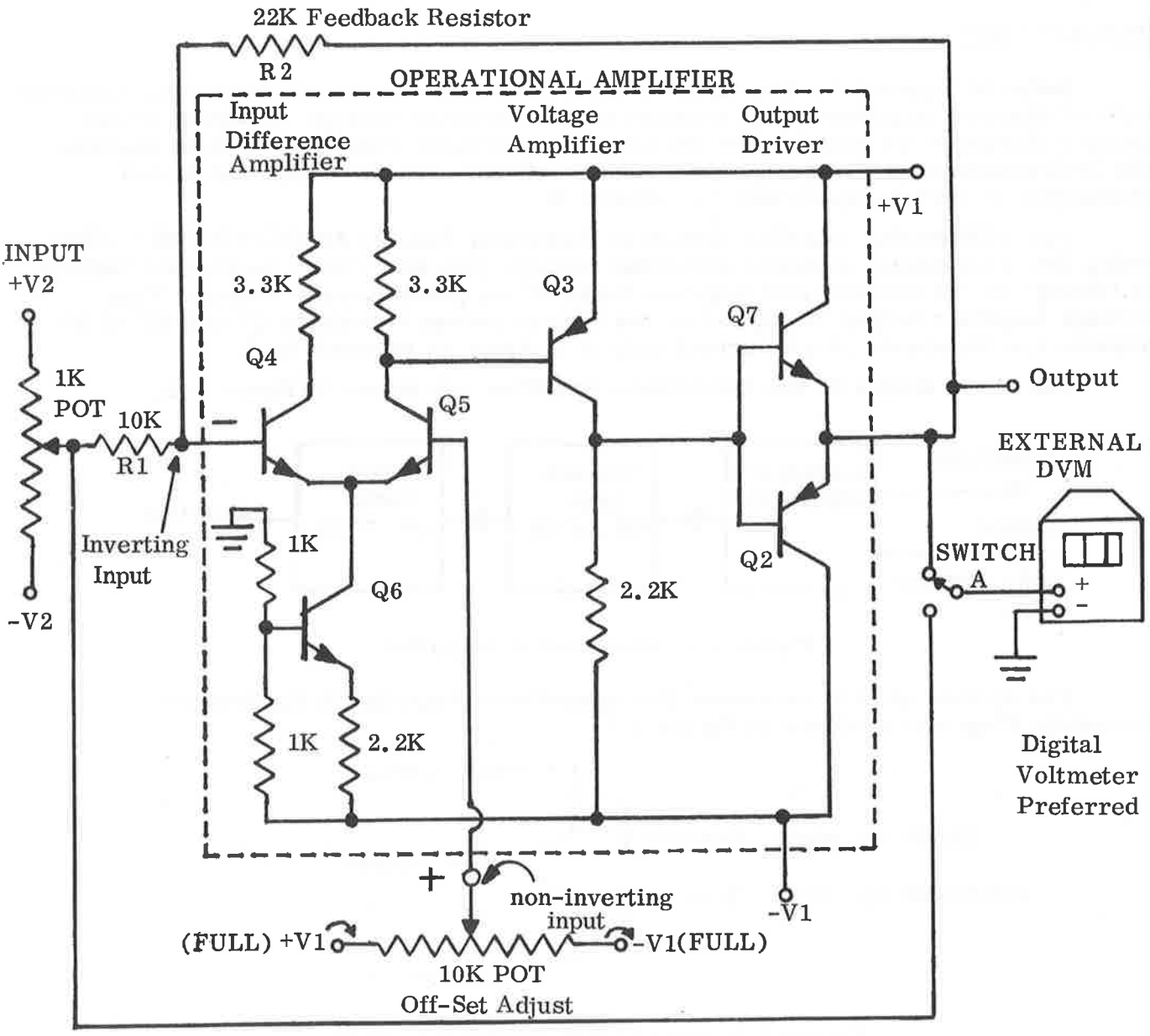


Figure 1-1 Discrete Op-Amp

OBJECTIVE:

You will build a complete discrete transistor OPERATIONAL AMPLIFIER. You will then measure the voltage gain of the system using input and feedback resistors.

DESCRIPTION:

Refer to figure 1-1. The circuit inside the dotted box is an Operational Amplifier built of discrete components. It consists of a Differential Voltage Amplifier circuit using trainsistors Q4 and Q5 with Q6 used in a Constant Current circuit to improve the Differential Amplifier performance. These circuits are discussed and tested thoroughly in Unit 6 Experiment No. 20 and 21.

The Differential Amplifier drives an additional Voltage Amplifier/Level Shifter using Q3. This circuit provides additional voltage gain and allows the Output Voltage to "swing" to the Positive and Negative limits of the power supply voltage. This Voltage Amplifier output is applied to the Output Driver transistor Q7 and Q2 which provide low impedance, high current output to drive an external load.

The three stages of the Operational Amplifier are shown in figure 1-2.

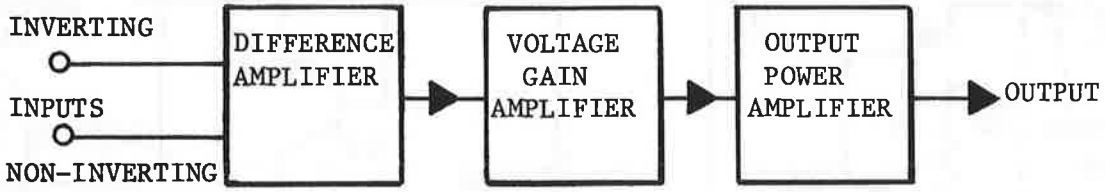


Figure 1-2 Operational Amplifier

The symbol used to represent the Operational Amplifier in Electronics Schematic Diagrams is shown in figure 1-3.

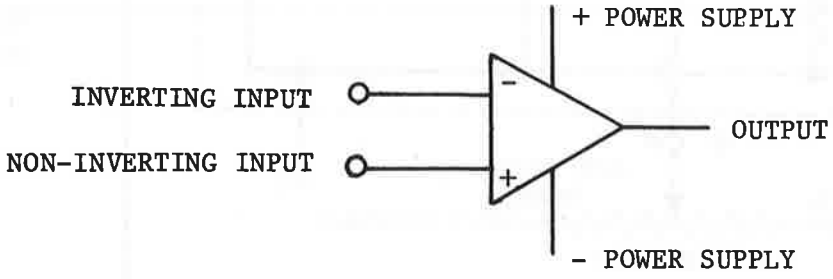


Figure 1-3 Operational Amplifier Symbol

The Operational Amplifier is a high gain differential amplifier with two inputs. The Non-Inverting Input (+) will generate an Output Signal IN-PHASE with the Input Signal. When the Non-Inverting Input INCREASES the Output Voltage will INCREASE.

The Inverting Input (-) will generate an Output Signal 180° OUT OF PHASE with the Input Signal. When the Inverting Input INCREASES the Output Voltage will DECREASE.

In the schematic of figure 1-1 the Operational Amplifier is shown inside the Dashed Line. The 1K Input Voltage Potentiometer is connected to the Inverting Input through the 10K Input Resistor. The Non-Inverting Input is connected to a 10K potentiometer which provides an adjustable D.C. voltage used as an OFFSET ADJUSTMENT. The Input Voltage or the Output Voltage is measured on the Meter by operating the SWITCH A.

This Operational Amplifier circuit has an additional important component, the FEEDBACK RESISTOR, which is connected from the Op-Amp Output to the Inverting Input. This resistor provides "Negative Feedback" to reduce the circuit gain and control the circuit Voltage Gain.

The Voltage Gain for this circuit is given by:

$$\text{GAIN} = \frac{V_{out}}{V_{in}} = -\frac{R2}{R1}$$

We can redraw the circuit in figure 1-1 using the symbol for the Operational Amplifier given in figure 1-3. The new schematic is shown in figure 1-4.

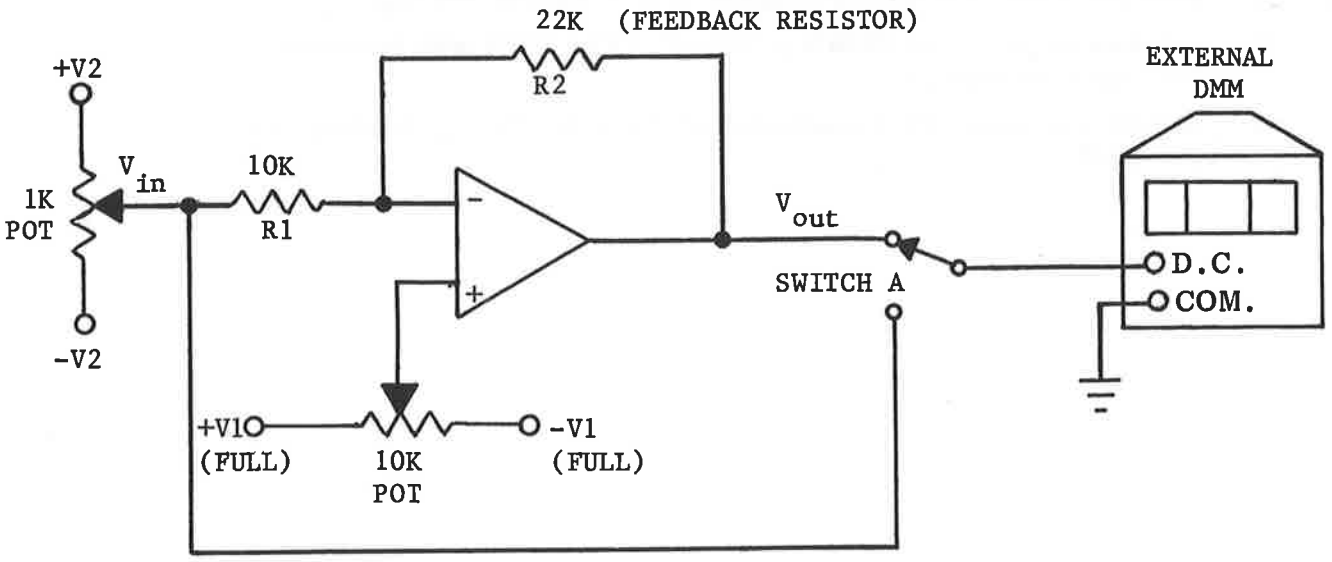


Figure 1-4 Operational Amplifier Circuit

$$\text{GAIN} = \frac{V_{out}}{V_{in}} = -\frac{R2}{R1} = -\frac{22K}{10K} = -2.2$$

Note that the Voltage Gain is Negative, meaning that the Output Voltage will be the reverse of the Input Voltage. Also note that the circuit gain depends only upon the ratio of the Feedback Resistor to the Input Resistor and not on the gain of the Operational Amplifier. By selecting the correct resistors we can achieve any gain desired. This is true as long as the Operational Amplifier Gain is very High. Further discussion of this circuit is available at the end of Experiment No. 2.

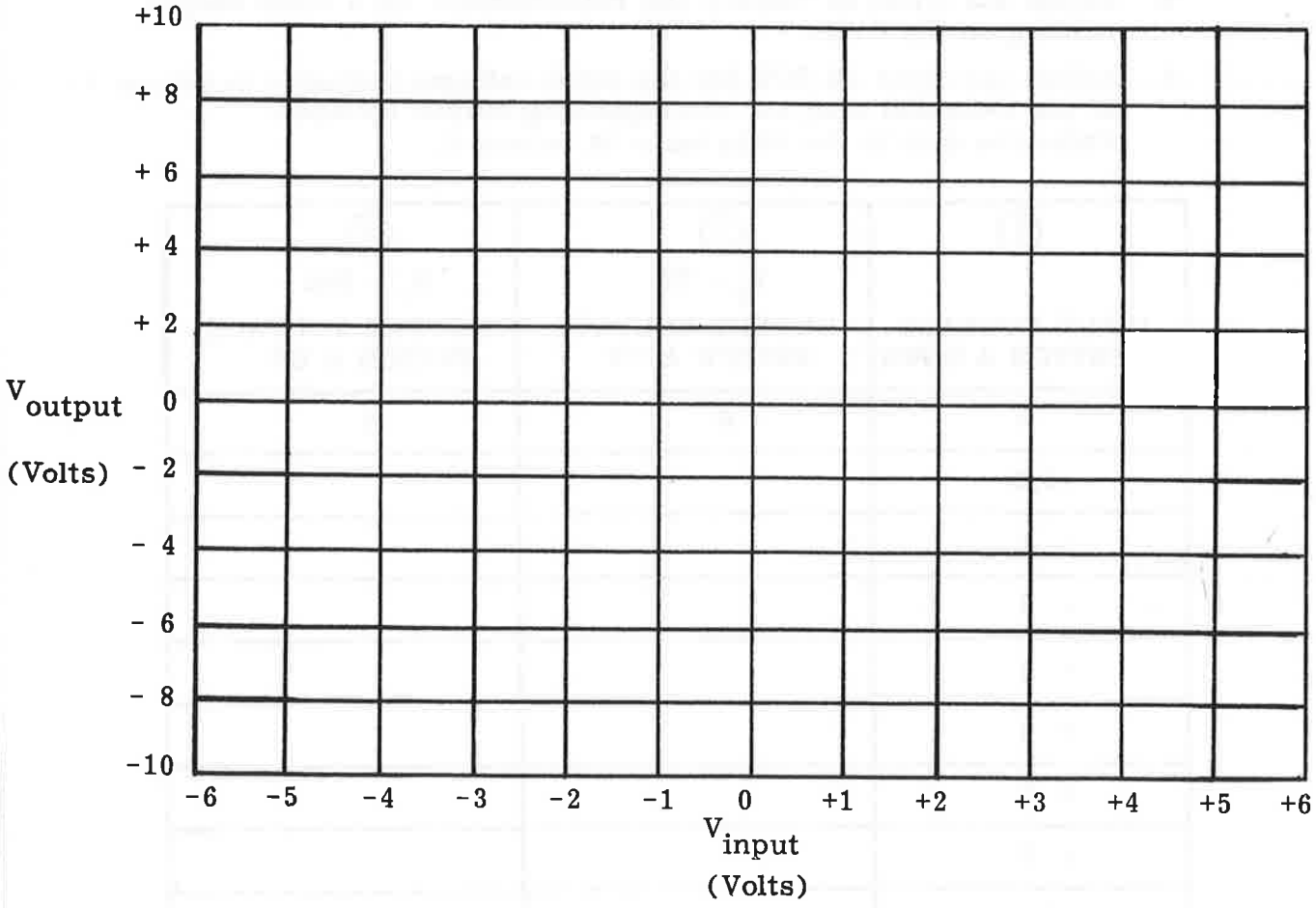
PROCEDURE:

1. Wire the circuit shown in Figure 1-1. Use 22K for R_f.
2. Set Switch A to the DOWN position. (The DVM will indicate the input voltage.)
3. Adjust the input 1K Potentiometer for a 0.00v V_{in} reading on the DVM.

4. Set Switch A to the UP position to read V_{out}.
5. Adjust the offset or balance 10K Potentiometer for a 0.00v output reading on the DVM.
6. Adjust the input 1K POT for the input voltages indicated in column 1 of the table and read the corresponding output voltages. Enter the data in the table below in column 2.

① INPUT VOLTAGE SWITCH A DOWN	② R_f = 22 OUTPUT VOLTAGE SWITCH A UP	③ R_f = 56K OUTPUT VOLTAGE SWITCH A UP
0	0	0
+0.5		
+ 1		
+ 2		
+ 3		
+ 4		
+ 5		
+ 6		
-0.5		
- 1		
- 2		
- 3		
- 4		
- 5		
- 6		

7. Plot the results on the graph below:



8. Measure the GAIN as the SLOPE of the above curve.

$$\text{GAIN} = \text{SLOPE} = \frac{\Delta V_{out}}{\Delta V_{in}} = \underline{\qquad\qquad}$$

G (For 22K) =

How does this compare with the theoretical calculated gain of 2.2?

9. Change the Feedback Resistor from 22K to 56K.
10. Repeat the Input and Output Measurements. Enter the V_{out} data in the table in column ③.
11. Plot the results for R_f = 56K on the same graph.

12. Measure the SLOPE to determine the measured gain.

FOR R_f = 56K $\quad G = \frac{\Delta V_{out}}{\Delta V_{in}} =$ _____

G (56K) =

13. The theoretical gain is $-\frac{R_f}{R_i} = \frac{-56K}{10K} = -5.6$

How does the measured gain above compare with 5.6?

QUESTIONS:

1. When R_f = 22K is used, at which input voltage did the amplifier saturate?
2. Is the plotted gain exactly equal to the calculated gain? If not, why is there a difference?
3. How can the gain of the circuit be adjusted?
4. Draw the symbol for an OP-AMP and label the inputs and outputs.
5. Draw an OP-AMP circuit with a gain of 10. Include the offset or bias POT, do not include the input POT.

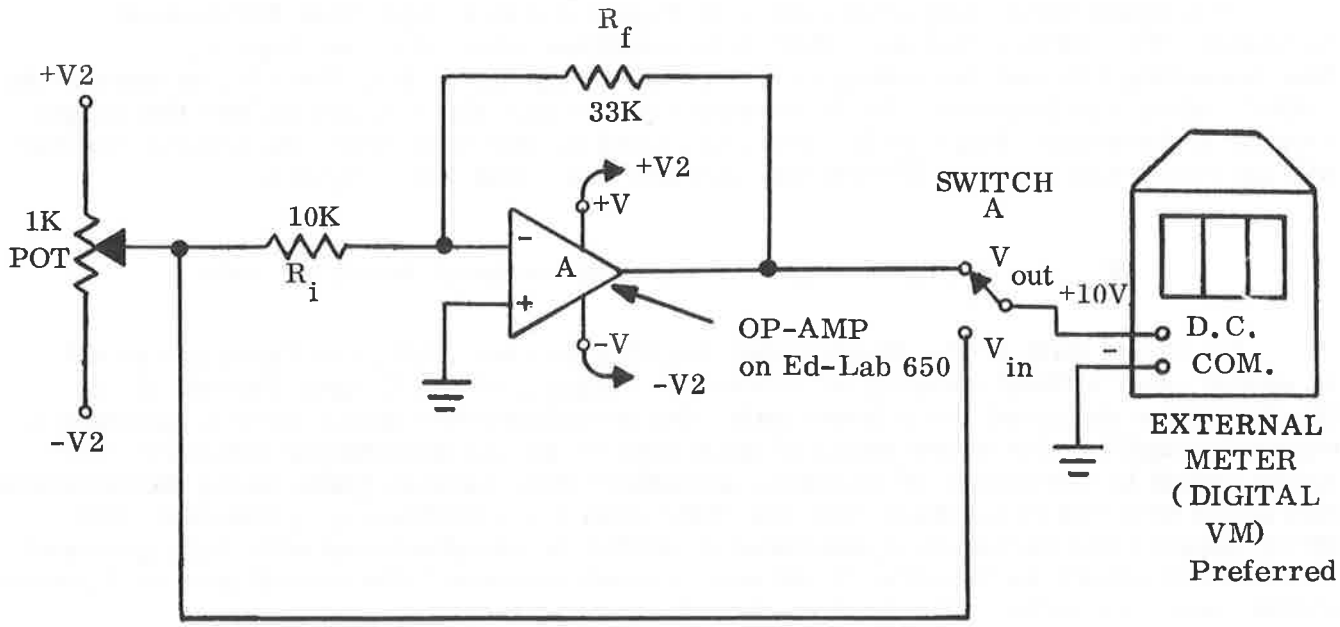


Figure 2-1 I.C. OP-AMP Inverter

OBJECTIVE:

You will use the internal Integrated Circuit OP-AMP located on the Ed-Lab 650 panel to provide an OP-AMP scaled Inverter circuit. You will then use an actual I.C. if one is available for the same circuit.

DESCRIPTION:

In this experiment it is not necessary to wire the OP-AMP circuit. An Integrated Circuit is mounted behind the OP-AMP Symbol on the Ed-Lab 650 panel. It is only necessary to connect the power inputs (+V & -V) and the external resistors. The (+) input will be connected to ground. The OP-AMP circuit has a negative gain and is thus called an INVERTER. The Gain "multiplies" the input voltage and therefore this circuit is also called a SCALER (or constant multiplier).

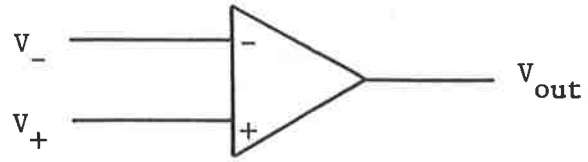


Figure 2-2 Operational Amplifier Symbol

The Operational Amplifier shown in figure 2-2 is a High Gain Differential Amplifier. The Differential Amplifier is an amplfiier which has two inputs, Non Inverting (+) and Inverting (-). An increasing signal into the + input causes the output voltage to Increase. An increasing voltage into the - input causes the output voltage to Decrease. When both inputs are used at the same time, the Output Voltage will be proportional to the Difference between the + and the - inputs.

$$V_{out} = A\,[V_+ - V_-] \qquad A = \text{Operational Amplifier Gain}$$

Since the gain of the Operational Amplfier is very high, the Op-Amp cannot be easily used without causing saturation or clipping of the Output Signal. If the Op-Amp were designed for a lower gain, the manufacturers would have to produce a separate amplifier for every value of gain needed by the electronics industry. This would result in thousands of different amplifiers with various gains being manufactured and could still fail to produce just the right gain for a particular application. For these reasons the standard Operational Amplifier is manufactured with high gain and a technique known as Negative Feedback is used to control the circuit gain and provide stable, accurate values of gain for a broad range of uses.

Negative Feedback is accomplished by connecting the Output Voltage to the Inverting Input through a Feedback Resistor. The circuit shown below is an operational amplifier circuit with Negative Feedback.

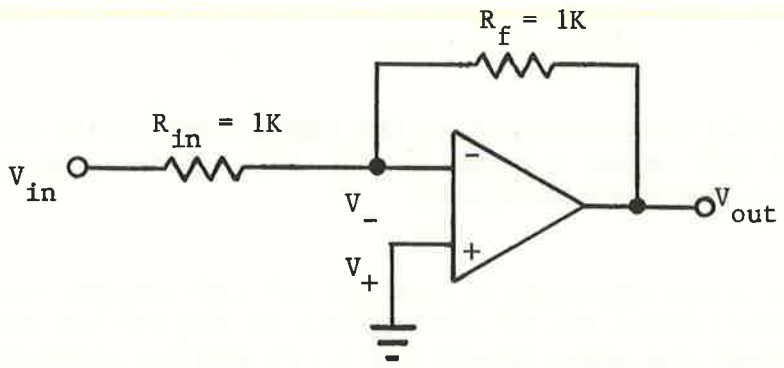


Figure 2-3 Operational Amplifier with Feedback

The connection of the Output Voltage to the Inverting Input reduces the gain of the circuit by adding some of the Output Voltage to the Inverting Input of the Op-Amp. This Feedback Voltage will reduce the circuit voltage gain.

Looking at the circuit shown in Figure 2-3 on Page 2, imagine that a V_{in} of 1 volt were applied. Without feedback, this 1 volt would be applied to V_ and amplified by the full Op-Amp gain (10,000 or more) and would result in the V_{output} going to the full NEGATIVE output swing. However, with feedback, the Negaive Output voltage will balance the positive input voltage at V_.

For the resistor values shown in the figure 2-3 this will occur when V_{out} = -1 volt. Notice we consider the input impedance to the Op-Amp to be very high. Therefore, we can consider it to be an open circuit and the balance of voltages is shown below:

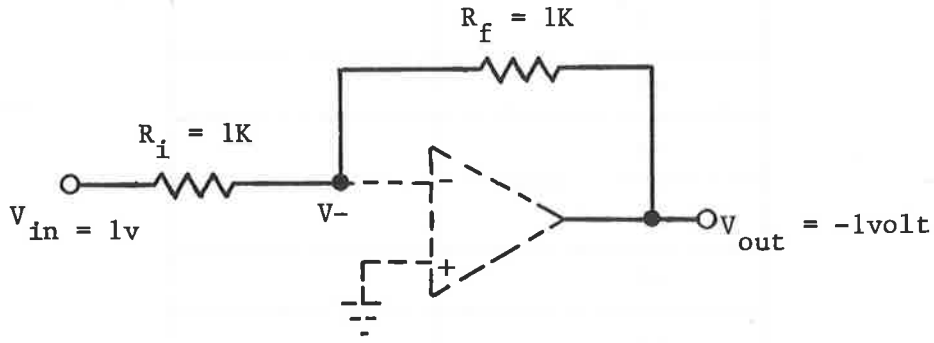


Figure 2-4 Operational Amplifier Circuit

V_ will be 0 volts (the +1 volt input is balanced by the -1 volt output).

Actually this example is only approximate. If the Op-Amp gain were 100,000 than V_ would be 0.00001 volts or 0.01 millivolts in order to produce a -1 volt output so the Output Voltage would actually be -0.99999 volts instead of -1 volts.

If we neglect the slight inaccuracy caused by the slight voltage on V_ needed to produce the output voltage then we would say the circuit has a gain of -1. For various values of R_i and R_f the circuit gain is given by:

$$\text{GAIN} = -\frac{R_f}{R_i}$$

The proof of this is given at the end of this experiment.

PROCEDURE:

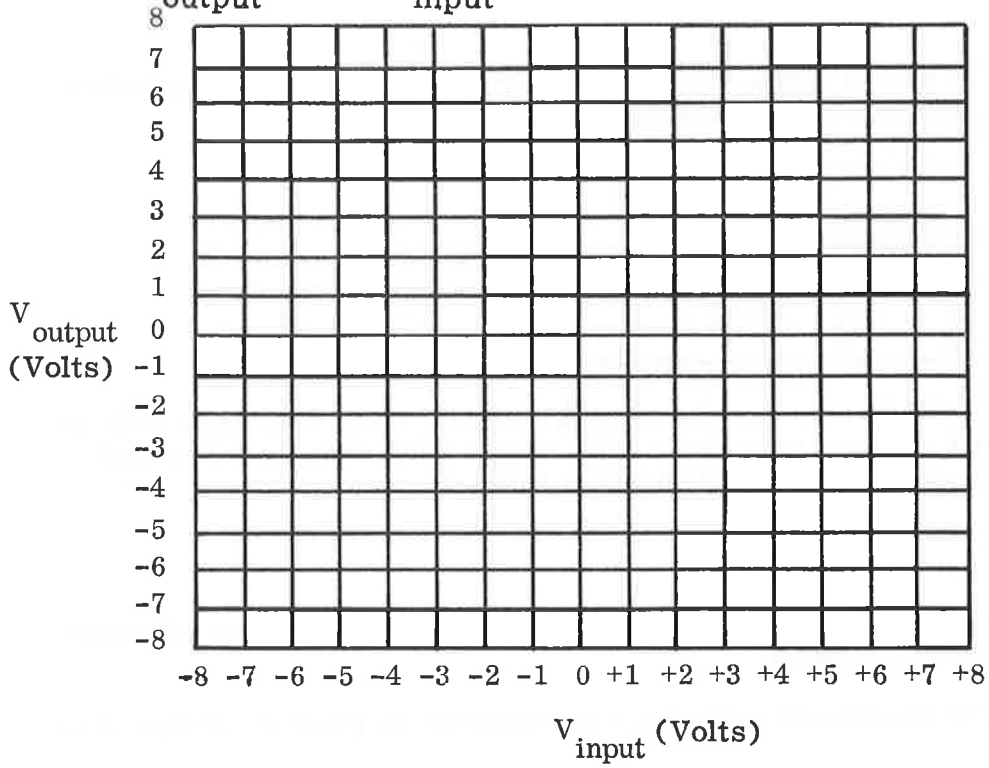
1. Wire the circuit in Figure 2-1. Use a Digital Voltmeter if one is available to simplify reading positive and negative voltages.

2. Vary the input voltage and read the output voltages. Enter the results in the table below.

V input (volts) SWITCH A DOWN	V output (volts) SWITCH A UP
0	
$+\frac{1}{2}$	
+1	
+2	
+3	
+4	
+5	
+6	
$-\frac{1}{2}$	
-1	
-2	
-3	
-4	
-5	
-6	

3. Plot the results on the graph on the following page.

GRAPH (V_{output} versus V_{input})



4. Measure the OP-AMP Circuit Gain as the slope of the curve plotted in step 3.

$$GAIN = \frac{\Delta V_{out}}{\Delta V_{in}} = \frac{(\quad) - (\quad)}{(\quad) - (\quad)} = \underline{\qquad\qquad} =$$

GAIN =

5. Calculate the expected gain as the ratio of the two resistors:

$$\text{Expected Gain} = -\frac{R_f}{R_{in}} = \underline{\qquad\qquad} =$$

Expected Gain =

6. How does the expected gain compare to the measured gain?

7. How does the wiring using the internal OP-AMP compare in complexity to wiring using the discrete components?

8. Remove R_f = 33K and Substitute R_f = 470K.

9. Calculate the expected gain.

G (R_f = 470K) =

10. Set Switch A UP to observe the output voltage, vary the input voltage (1K POT) and observe that the output jumps very sharply. It is not desireable or easy to measure the gain this way.

QUESTIONS:

1. Why are Integrated circuit OP-AMPS used instead of building OP-AMPS with discrete components.

2. Is the gain of the circuit tested in this experiment Positive or Negative?

3. Are the input impedances of the inverting and non-inverting inputs to an OP-AMP High or Low?

OPERATIONAL AMPLIFIERS

The Operational Amplifier is a High Gain Diffential Amplifier circuit. These devices are available in Integrated Circuits and are very widely used in modern electronics.

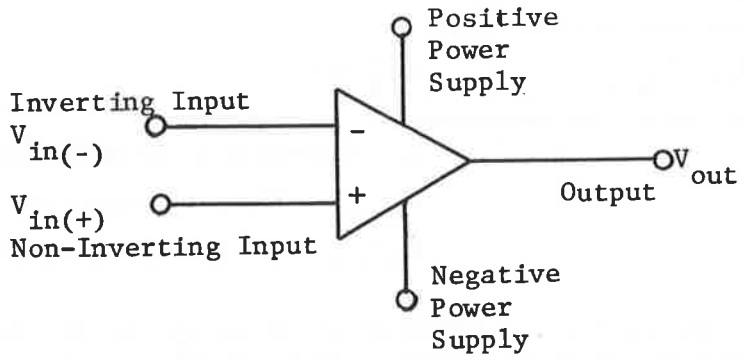


Figure 2-5 Operational Amplifier Symbol & Terminals

The Operational Amplfier has the following characteristics:

1. Very high Voltage Gain
2. Very high Input Impedance for the Inverting and Non-Inverting Inputs.

The Output Voltage caused by a voltage applied to the Inverting Input is:

$$V_{out} = -A \times V_{in(-)}$$

A = Operational Amplfiier Gain

$V_{in(-)}$ = Input Voltage to Inverting Input

Note that the Output Voltage is Negative with respect to the Inverting Input Voltage. This means that when the Inverting Input voltage INCREASES the Output voltage will DECREASE.

The Output Voltage caused by a voltage applied to the Non-Inverting Input is:

$$V_{out} = A \times V_{in(+)}$$

A = Operational Amplifier Gain

$V_{in(+)}$ = Input Voltage to Non-Inverting Input

Note that the Output Voltage is Positive with respect to the Non-Inverting Input Voltage. This means that when the Non-Inverting Input Voltage INCREASES the Output Voltage will INCREASE.

Both the Inverting and the Non-Inverting Inputs to the Operational Amplifier may be used at the same time. Each input voltage will cause an output voltage and the total Output Voltage will be:

$$V_{out} = A [V_{in(+)} - V_{in(-)}] \quad \text{EQ 1}$$

A = Operational Amplifier Gain

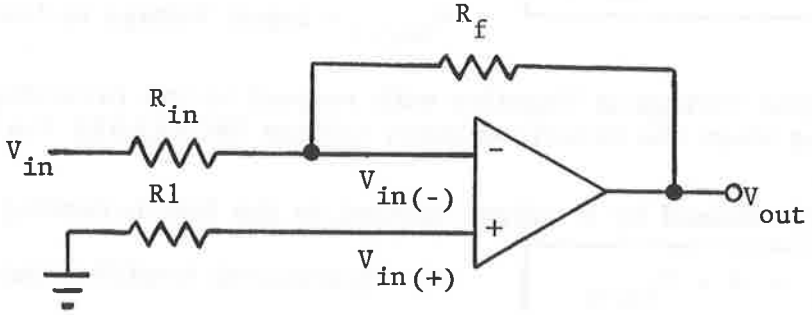
$V_{in(+)}$ = Non-Inverting Input Voltage

$V_{in(-)}$ = Inverting Input Voltage

The Operational Amplifier Output Voltage is given by the Op-Amp Gain, A times the difference between the Non-Inverting Input Voltage and the Inverting Input Voltage. This is the feature of a Differential Amplifier.

The actual Output Voltage of the Operational Amplfiier is limited to the voltage of the Op-Amp Power Supply Voltage. Typcial Op-Amps use 15 volt positive and negative supplies so the maximum output voltage would be 15 volts positive and negative.

Operational Amplifiers are intentionally designed and built to have very high Voltage Gain. The typical voltage gain for an integrated circuit Op-Amp is between 10,000 and 100,000. Normally a single stage amplifier gain of such a high magnitude is not needed and is not desirable. The reason that Operational Amplifiers are designed with very high voltage gain is that the Operational Amplifier is used in a Negative Feedback circuit. Negative Feedback is used to stabilize the circuit gain and to make the circuit gain independent of the particular operational amplifier gain. The Operational Amplifier with Feedback is shown below:



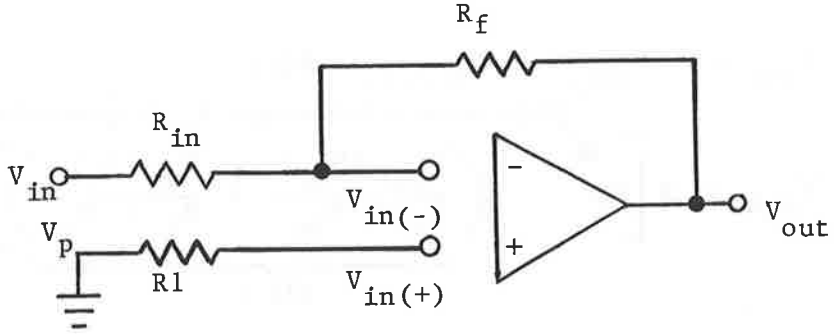
Note that the Output Voltage is connected back into the Inverting Input through the Feedback Resistor R_f. This connection causes the Output Voltage to be injected into the Inverting Input, which will reduce the Output Voltage. Recall that the Output Voltage and Inverting Input voltage are 180° out of phase with each other, so this Negative Feedback will reduce the circuit gain. In fact, Negative Feedback will cause the circuit gain to be:

$$\text{GAIN} = -\frac{R_f}{R_{in}}$$

We will now prove the above gain equation:

$$V_{out} = A\left[(V_{in(+)} - V_{in(-)}\right] \quad \text{stated previously}$$

We mentioned earlier that the characteristics of the Operational Amplfier included very high Input Impedance for the Inverting and Non-Inverting Inputs. These input impedances are so high, in fact, that they can be considered as open circuits and we can redraw the circuit as shown below.



The $V_{in(-)}$ and $V_{in(+)}$ connections are shown separated from the Op-Amp symbol to indicate that the + and - inputs to the Op-Amp are treated as open circuits.

If V_{in} were connected to ground the voltage at $V_{in(-)}$ caused by V_{out} can be calculated using the Voltage Divider Equation.

$$V_{in(-)} \text{ (caused by } V_{out}) = \frac{V_{out} \times R_{in}}{R_f + R_{in}}$$

If V_{out} were connected to ground the voltage at $V_{in(-)}$ caused by V_{in} can be calculated using the Voltage Divider Equation.

$$V_{in(-)} \text{ (caused by } V_{in}) = \frac{V_{in} \times R_f}{R_f + R_{in}}$$

If both voltages are operating then the voltage at $V_{in(-)}$ will be the sum of the voltages caused by each.

$$V_{in(-)} = \frac{V_{out}\,(R_{in})}{R_f + R_{in}} + \frac{V_{in}\,(R_f)}{R_f + R_{in}} \qquad \text{EQ 2}$$

The voltage at $V_{in(+)}$ caused by Vp is 0 volts because Vp is connected to ground.

$$V_{in(+)} = Vp = 0 \qquad \text{EQ 3}$$

We can use these values of $V_{in(+)}$ and $V_{in(-)}$ in the formula shown earlier for V_{out}

$$V_{out} = A\,(V_{in(+)} - V_{in(-)}) \qquad \text{EQ 1}$$

This term = 0 because V_p is grounded

$$V_{out} = A\left[Vp - \underbrace{\left(\frac{V_{out}\,(R_{in})}{R_f + R_{in}} + \frac{V_{in}\,(R_f)}{R_f + R_{in}}\right)}_{\text{EQ 2}}\right]$$

$$V_{out} = A\left[-\frac{V_{out}\,(R_{in})}{R_f + R_{in}} - \frac{V_{in}\,(R_f)}{R_f + R_{in}}\right]$$

We can divide both sides of the equation by the Op-Amp Voltage Gain A.

$$\frac{V_{out}}{A} = -\frac{V_{out}\,R_{in}}{R_f + R_{in}} - \frac{V_{in}\,R_f}{R_f + R_{in}}$$

A, the Op-Amp gain is very large (10,000 or more) so the expression V_{out}/A will be very small. We will neglect this small value and call it zero.

$$0 = -\frac{V_{out}\,R_{in}}{R_f + R_{in}} - \frac{V_{in}\,R_f}{R_f + R_{in}}$$

$$\frac{V_{out}\ R_{in}}{R_f + R_{in}} = -\frac{V_{in}\ R_f}{R_f + R_{in}}$$

We can multiply both sides of the equation by $R_f + R_{in}$.

$$V_{out}\ R_{in} = -V_{in}\ R_f$$

This equation can be solved for the Voltage Gain.

$$\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

$$\text{GAIN} = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

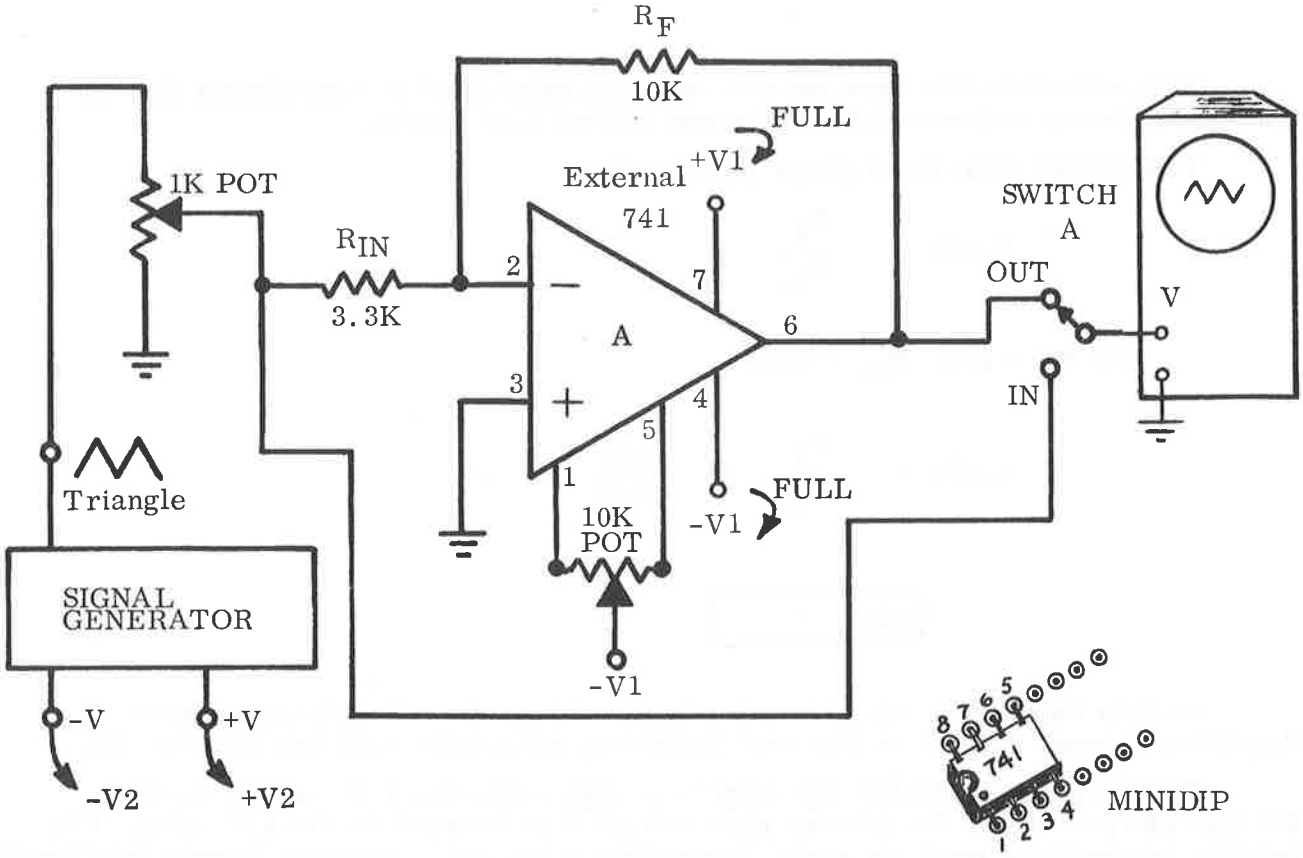


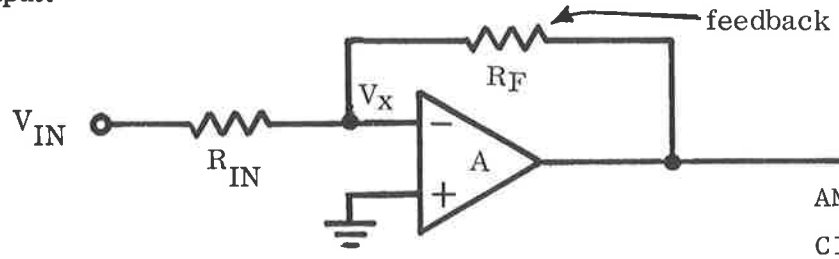
Figure 3-1 Operational Amplifier

Objective:

You will use a LINEAR INTEGRATED CIRCUIT Operational Amplifier in a Scaled Inverter Circuit.

Description:

Linear Integrated Circuits are ANALOG or varying voltage devices rather than DIGITAL or ON/OFF circuits. A typical Linear I.C. is the OPERATIONAL AMPLIFIER or DIFFERENCE AMPLIFIER. This circuit is usually a very High Gain Amplifier and is used with input and feedback resistors and components for computation and control and signal processing. An amplifier circuit is shown below with a fixed + input (ground) and with an input and feedback resistor connected to the - input.



AMPLIFIER GAIN = A

CIRCUIT GAIN = $-\frac{R_f}{R_{in}}$

Figure 3-2 FEEDBACK OP-AMP

This circuit is the same as that configuration used in Experiment No. 2. The same theory and calculations for the circuit gain apply.

The circuit gain is as given previously

$$\text{GAIN} = -\frac{R_F}{R_{in}}$$

for $R_F = 10K$, $R_{in} = 3.3K$

$$\text{GAIN} = -\frac{R_F}{R_{in}} = -\frac{10K}{3.3K} = -3$$

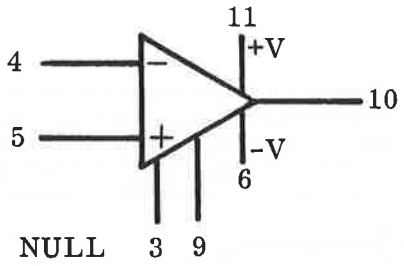
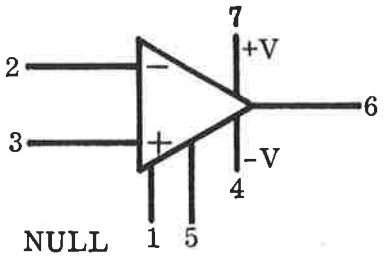
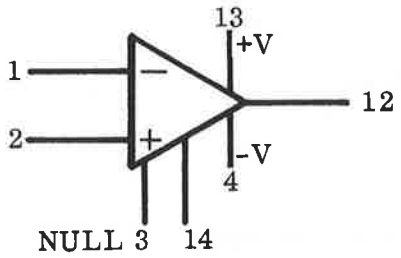
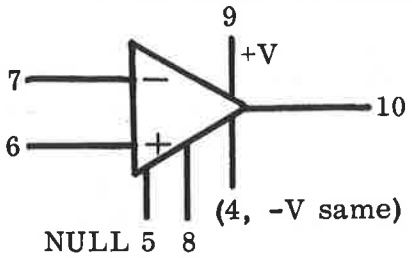
$$\boxed{\text{GAIN} = -3}$$

In this experiment an external plug-in Integrated Circuit Operational Amplifier is used instead of the unit internally mounted inside the Ed-Lab 650.

The Integrated Circuit Op-Amp is plugged into the I.C. socket on the Ed-Lab 650 panel and the banana pins are used to connect to the I.C. pins. The correct connections must be made, depending upon the particular Integrated Circuit used. Figure 3-1 shows the correct pin numbers for the 741 minidip I.C.

Careful Note: The pin numbers on the minidip I.C. do not correspond to the banana jack numbers for pins 5,6,7 and 8 because the minidip is an 8 pin I.C. package.

The OP-AMP used in this experiment is the model number 741. There are three different DIP (Dual-in-Line Package) Pin Layouts as summarized below:

14 PIN DIP 741	
8 PIN DIP 741	
14 PIN DIP TWO 741 (Model NO. 747)	 

The specification sheets for the 741 and 747 OP-AMPs are given on the following two pages.

μA741

FREQUENCY-COMPENSATED OPERATIONAL AMPLIFIER

LINEAR INTEGRATED CIRCUITS

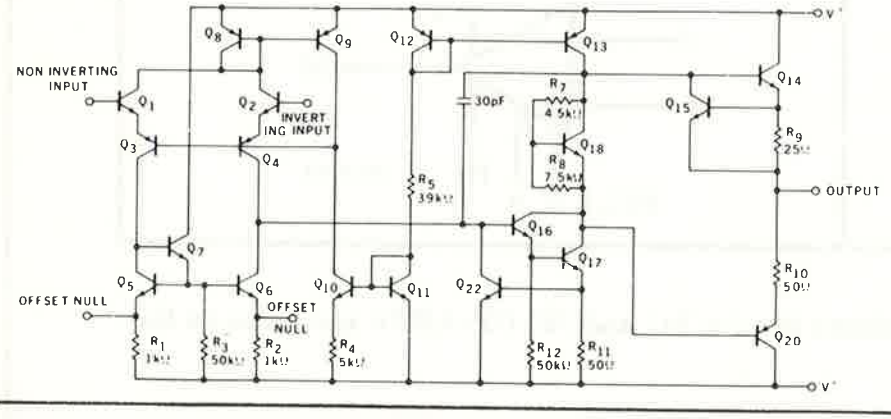
GENERAL DESCRIPTION — The μA741 is a high performance monolithic operational amplifier constructed on a single silicon chip, using the Fairchild Planar* epitaxial process. It is intended for a wide range of analog applications. High common mode voltage range and absence of "latch-up" tendencies make the μA741 ideal for use as a voltage follower. The high gain and wide range of operating voltage provides superior performance in integrator, summing amplifier, and general feedback applications.

- **NO FREQUENCY COMPENSATION REQUIRED**
- **SHORT-CIRCUIT PROTECTION**
- **OFFSET VOLTAGE NULL CAPABILITY**
- **LARGE COMMON-MODE AND DIFFERENTIAL VOLTAGE RANGES**
- **LOW POWER CONSUMPTION**
- **NO LATCH UP**

ABSOLUTE MAXIMUM RATINGS

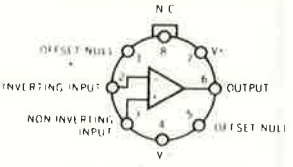
Supply Voltage	
Military (312 Grade)	±22 V
Commercial (393 Grade)	±18 V
Internal Power Dissipation (Note 1)	
Metal Can	500 mW
Ceramic DIP	670 mW
Silicone DIP	340 mW
Mini DIP	310 mW
Flatpak	570 mW
Differential Input Voltage	±30 V
Input Voltage (Note 2)	±15 V
Storage Temperature Range	
Metal Can, Ceramic DIP, and Flatpak	−65°C to +150°C
Mini DIP and Silicon DIP	−55°C to +125°C
Operating Temperature Range	
Military (312 Grade)	−55°C to +125°C
Commercial (393 Grade)	0°C to + 70°C
Lead Temperature (Soldering)	
Metal Can, Ceramic DIP and Flatpak (60 seconds)	300°C
Mini DIP and Silicone DIP (10 seconds)	260°C
Output Short Circuit Duration (Note 3)	Indefinite

EQUIVALENT CIRCUIT



CONNECTION DIAGRAMS
(TOP VIEW)

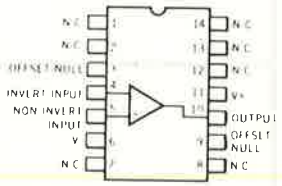
8 LEAD METAL CAN



NOTE: PIN 4 CONNECTED TO CASE

ORDER PART NOS.
U5B7741312
U5B7741393

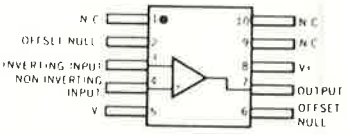
14 LEAD DIP



FOR CERAMIC DIP ORDER PART NOS.
U6A7741312
U6A7741393

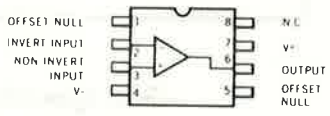
FOR SILICONE DIP ORDER PART NO.
U9A7741393

FLATPACK



ORDER PART NO.
U3F7741312

MINIDIP



ORDER PART NO.
U9T7741393

*Planar is a patented Fairchild process.

μA747

DUAL FREQUENCY COMPENSATED OPERATIONAL AMPLIFIER

LINEAR INTEGRATED CIRCUITS

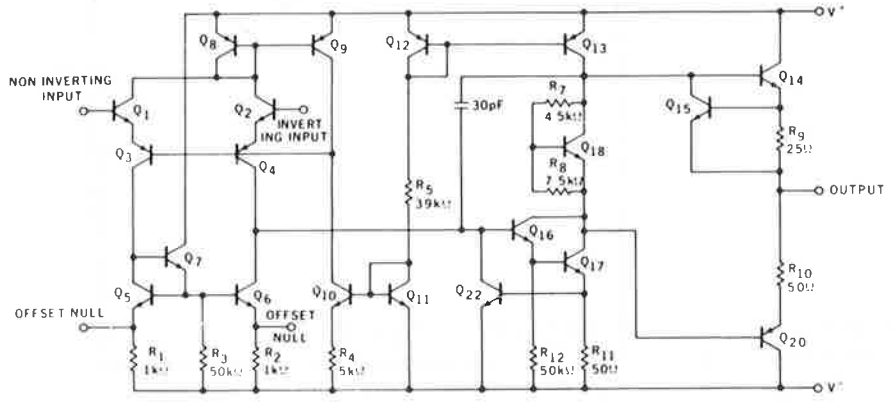
GENERAL DESCRIPTION – The μA747 is a pair of high performance monolithic operational amplifiers constructed on a single silicon chip, using the Fairchild Planar* epitaxial process. They are intended for a wide range of analog applications where board space or weight are important. High common mode voltage range and absence of "latch-up" make the μA747 ideal for use as a voltage follower. The high gain and wide range of operating voltage provides superior performance in integrator, summing amplifier, and general feedback applications. The μA747 is short-circuit protected and requires no external components for frequency compensation. The internal 6 dB/octave roll-off insures stability in closed loop applications. For single amplifier performance, see μA741 data sheet.

- **NO FREQUENCY COMPENSATION REQUIRED**
- **SHORT-CIRCUIT PROTECTION**
- **OFFSET VOLTAGE NULL CAPABILITY**
- **LARGE COMMON-MODE AND DIFFERENTIAL VOLTAGE RANGES**
- **LOW POWER CONSUMPTION**
- **NO LATCH UP**

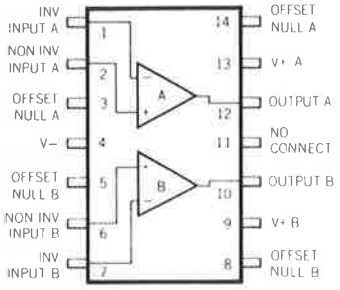
ABSOLUTE MAXIMUM RATINGS

Supply Voltage	
Military (312 Grade)	±22 V
Commercial (393 Grade)	±18 V
Internal Power Dissipation (Note 1)	
Metal Can	500 mW
Ceramic DIP	670 mW
Differential Input Voltage	±30 V
Input Voltage (Note 2)	±15 V
Voltage between Offset Null and V⁻	±0.5 V
Storage Temperature Range	−65°C to +150°C
Operating Temperature Range	−55°C to +125°C
Lead Temperature (Soldering, 60 seconds)	300°C
Output Short-Circuit Duration (Note 3)	Indefinite

EQUIVALENT CIRCUIT (Each Side)

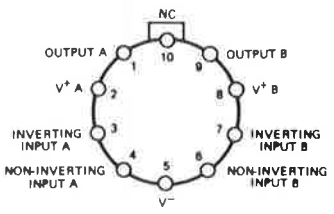


CONNECTION DIAGRAMS
(TOP VIEWS)
14 LEAD DIP



ORDER PART NOS.
U7A7747312
U7A7747393

10 LEAD METAL CAN



ORDER PART NOS.
U5F7747312
U5F7747393

*Planar is a patented Fairchild process.

Procedure:

1. Wire the circuit shown in Figure 3 - 1.* The pin numbers are given for the MINIDIP 8 pin DIP. If you are using the full-size DIP or the DUAL OP-AMP, substitute different pin numbers. Switch A is used to select the Output Voltage (UP), or the Input Voltage (DOWN).

2. Adjust the NULL OFF-SET POT (10K POT) by setting $V_{in} = 0$ (1K POT to zero).

   Observe the output signal, Switch A UP. Momentarily remove one lead of the 10K feedback resistor and adjust the 10K POT for an output which corresponds to the balance where the scope output jumps up and down between maximum and minimum voltages.

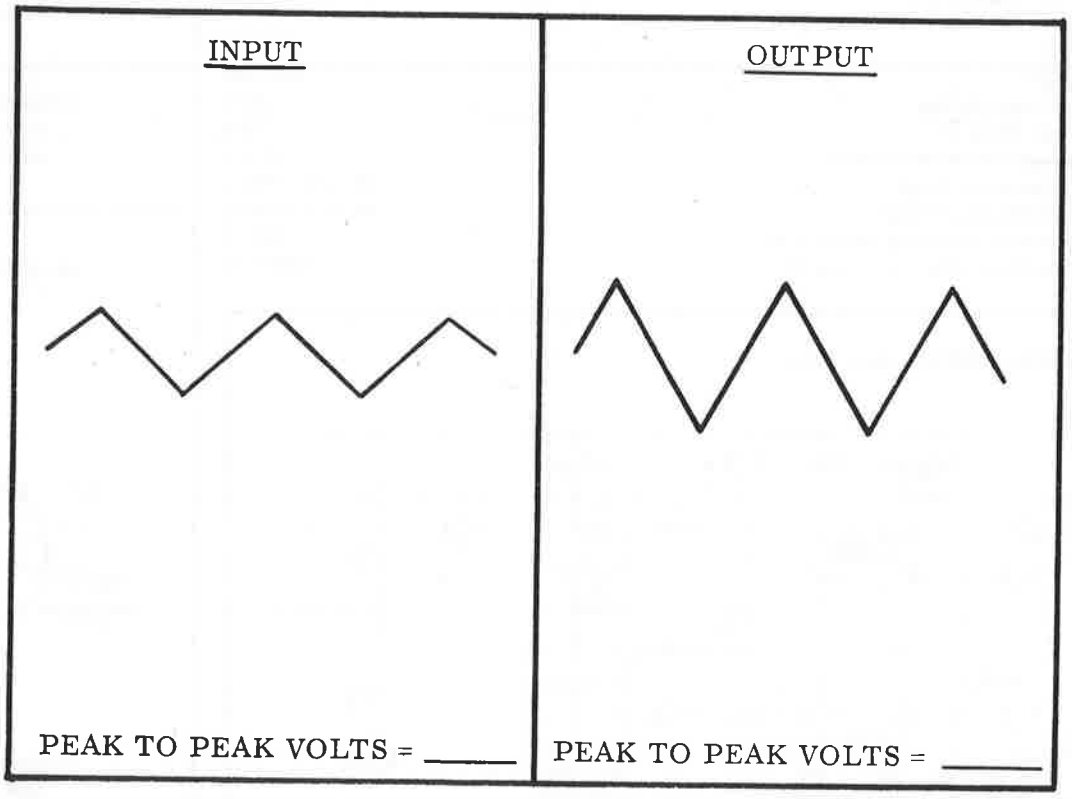
   Replace the 10K feedback resistor lead.

   The Null Off-Set is now adjusted.

3. Vary the input voltage to a convenient level and read the input and output voltage peak to peak levels on the oscilloscope.

   Be sure that the output and input triangle waveform is not clipped or distorted. Enter the data below:

WAVEFORMS



* If a 741 is not available, use the OP-AMP on the Ed-Lab panel. This internal Op-Amp has an internal null off-set. You can thus skip Step 2 above.

4. Calculate the system gain:

$$\text{GAIN} = \frac{V_{output}}{V_{input}} = _____$$

GAIN =

5. How does the MEASURED GAIN compare with the designed gain of -3? What is the output voltage variation range? What is the input voltage variation range?

6. What would the gain be for the following resistor combinations? Enter your calculation in the third column below:

R_{IN}	R_F	CALCULATE GAIN	MEASURE GAIN
3.3K	10K		
3.3K	3.3K		
3.3K	33K		
3.3K	100K		
3.3K	1K		
3.3K	100K POT		
10K	33K		
10K	1M POT		

7. Substitute the above resistors and measure the gain. How do the measured gains compare with the calculated gains?

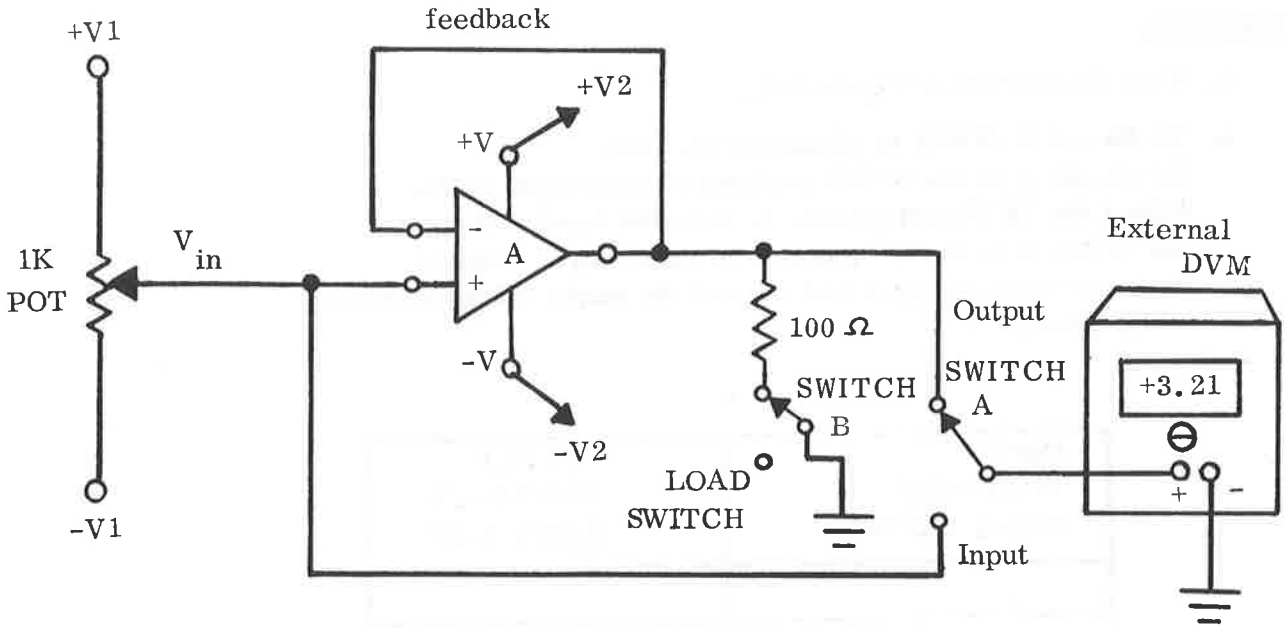


Figure 4-1 Voltage Follower Circuit

USE DIGITAL VOLTMETER if available or Ed-Lab panel meter. (Reverse leads for negative voltages.)

OBJECTIVE:

You will connect an OP-AMP as a Voltage Follower. You will plot the input and output voltage Transfer Curve. You will measure the input and output impedances.

DESCRIPTION:

The Voltage Follower is a circuit used as a "Buffer". The very high input impedance or resistance prevents loading of the input source; and the very low output impedance permits the OP-AMP to drive relatively high current loads or low load impedances or resistances. Circuit gain is a positive 1 or "unity". The input is connected to the Amplifier + input. The 1K POT is used to vary the input DC Voltage. The 100 ohm resistor is a LOAD and Switch B places the Load in and out of the circuit. Switch A is used to measure the output voltage (UP) or the input voltage (DOWN).

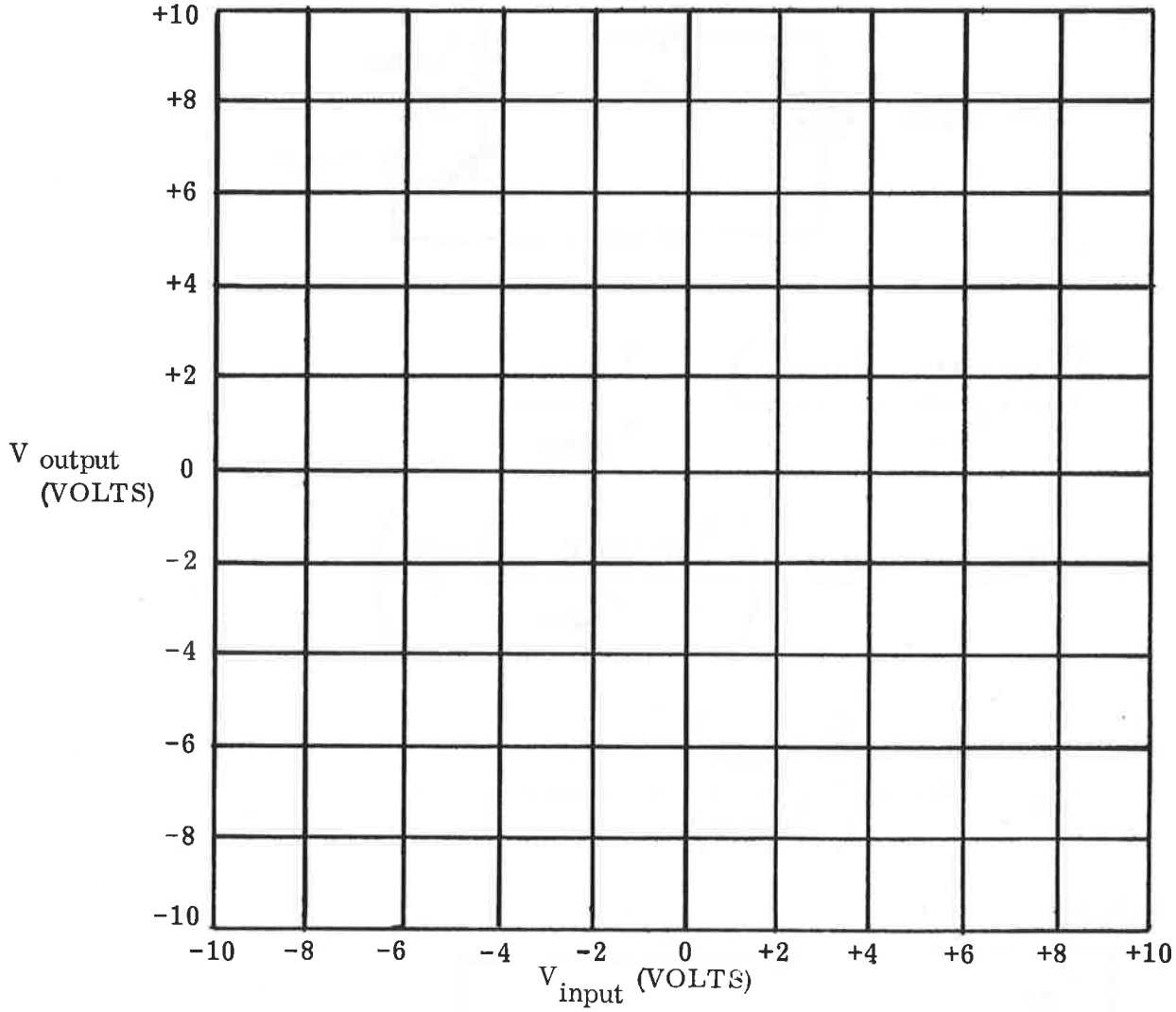
A detailed explaination of the Voltage Follower circuit is included at the end of this experiment.

PROCEDURE:

1. Wire the circuit in Figure 4-1.
2. Set Switch B DOWN to eliminate the load.
   Set Switch A to the DOWN position to read input volts.
   Adjust the 1K Potentiometer to vary the input voltage.
   Set Switch A to the UP position to read output voltage.
   Vary the input voltages and record the output voltages in the table below.

INPUT VOLTAGES Switch A DOWN	OUTPUT VOLTAGES Switch A UP
0	
1	
2	
4	
6	
8	
-1	
-2	
-4	
-6	
-8	

3. Plot the results in the graph below:



4. Does the Voltage follower have a gain of 1?_____

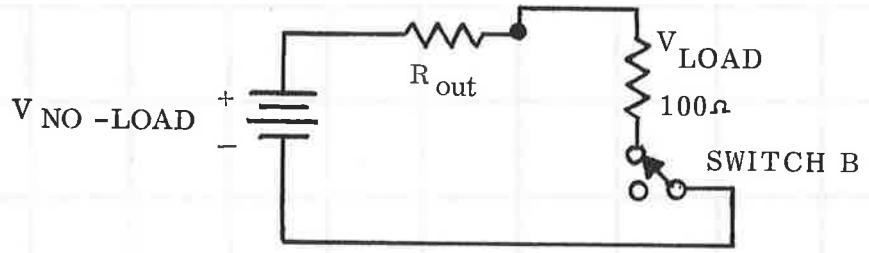
5. Determine the Output Impedance.
   Set Switch A UP to read the Output Voltage. Set 1K POT for an output reading of 4 volts.

$V_{NO-LOAD}$ = 4 VOLTS.

6. Now Set Switch B UP to insert a load of 100 ohms.
   What is the output voltage reading?

V_{LOAD} =

7. Calculate the Output Impedance Based on the following equations:



Since current in both resistors is the same:

$$\frac{\left(V_{NO\ LOAD} - V_{LOAD}\right)}{R_{out}} = \frac{V_{LOAD}}{R_{LOAD}}$$

$$\text{or} \quad R_{out} = R_{LOAD} \times \left(\frac{V_{NO\text{-}LOAD} - V_{LOAD}}{V_{LOAD}}\right)$$

$$R_{out} = 100\Omega \times \left(\frac{4\text{-}V_{LOAD}}{V_{LOAD}}\right) = _____ = _____$$

Calculate

R_{out} =

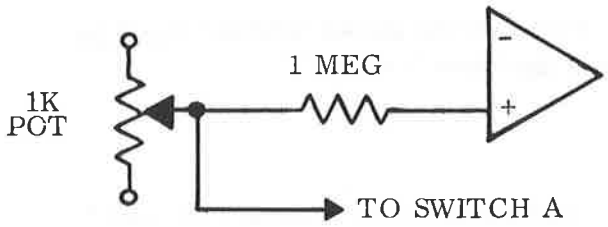
The output impedance should be low.

8. Determine the Input Impedance.
   Set Switch B DOWN to eliminate the LOAD.
   Set Switch A DOWN to read the INPUT Voltage.
   Set the 1K POT input for an input voltage of 4 volts.

V_1 = 4 VOLTS

   Check to make sure that the output voltage is also 4 volts, (i.e., Switch A UP).

9. Modify the circuit by inserting a 1 Megohm Resistor in series with the input + terminal as shown below:

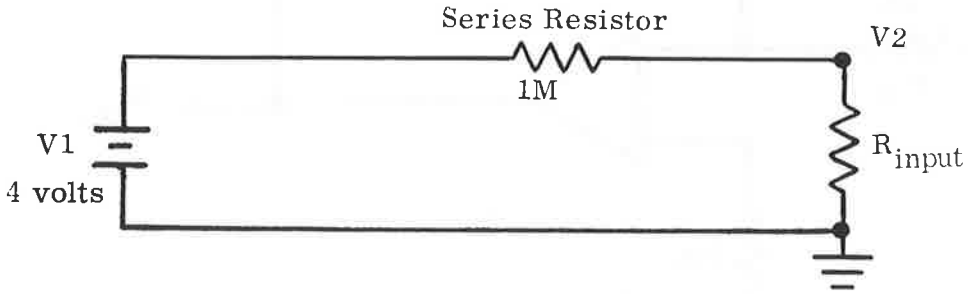


10. With Switch A DOWN, measure the INPUT voltage to make sure it is still 4 volts. Otherwise adjust it to be 4 volts.

11. Now set Switch A UP to measure and record the new output voltage resulting from the Input Load.

V_2 =

12. Calculate the input impedance from the following equations:



$$\frac{V_1 - V_2}{1M} = \frac{V_2}{R\ input}$$

$$R_{input} = 1M \times \frac{V_2}{V_1 - V_2} =$$

R_{input} =

The Input Impedance should be high.

QUESTIONS:

1. In a Voltage Follower circuit, is the output Voltage equal to, greater than, or less than the Input Voltage?

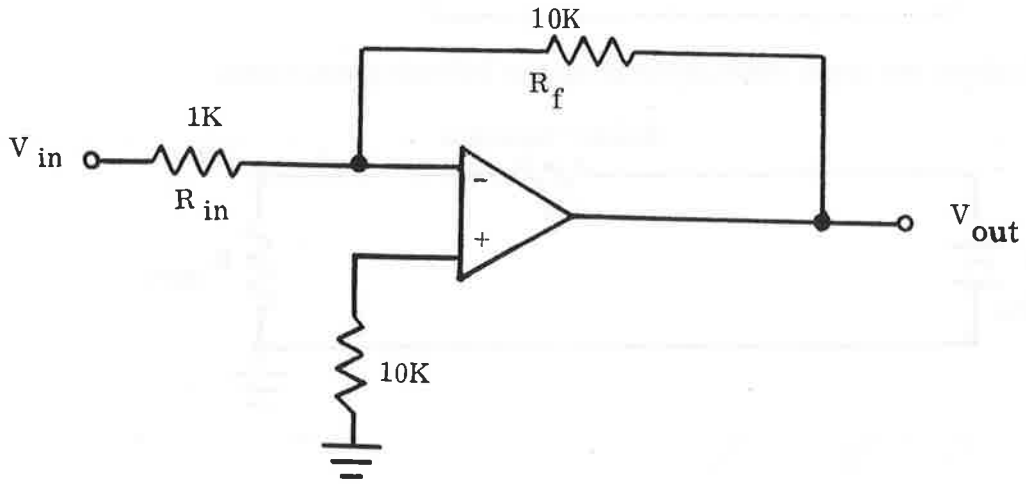
2. What is a buffer?

3. What is a typical output impedance for a Voltage Follower?

4. What is a typical input impedance for a Voltage follower?

5. Is the output voltage in phase, or out of phase, with the input voltage?

6. What is the input impedance of a standard negative gain OP-AMP circuit such as shown below with a gain of 10?



7. Can you name an application where a Voltage Follower would be used?

VOLTAGE FOLLOWER CIRCUIT ANALYSIS

In this circuit the input voltage is applied directly to the Non-Inverting input terminal of the Operational Amplifier. Feedback is directly connected from the Output of the Op-Amp to the Inverting Input. This feedback circuit is a Voltage Follower. The Output Voltage is the same as the Input Voltage.

For the circuit in figure 4-1

$V_{in} = V_+ =$ Non-Inverting Input Voltage

$V_{out} = V_- =$ Inverting Input Voltage

The Op-Amp is a high gain Differential Amplifier.

Therefore:

$V_{out} = A\,(V_+ - V_-)$ A = Operational Amplifier Voltage Gain

We can substitute V_{in} for V_+ and V_{out} for V_-

$$V_{out} = A\,(V_{in} - V_{out}) = A\,V_{in} - A\,V_{out}$$

This equation can be re-arranged to:

$$V_{out} + A\,V_{out} = A\,V_{in}$$

$$V_{out}\,(1 + A) = A\,V_{in}$$

$$\frac{V_{out}}{V_{in}} = \frac{A}{1 + A}$$

If A is very large then $\frac{A}{1 + A} = 1$

$$\boxed{\frac{V_{out}}{V_{in}} = \text{GAIN} = 1}$$

Ed-Lab

A.C. VOLTAGE FOLLOWER

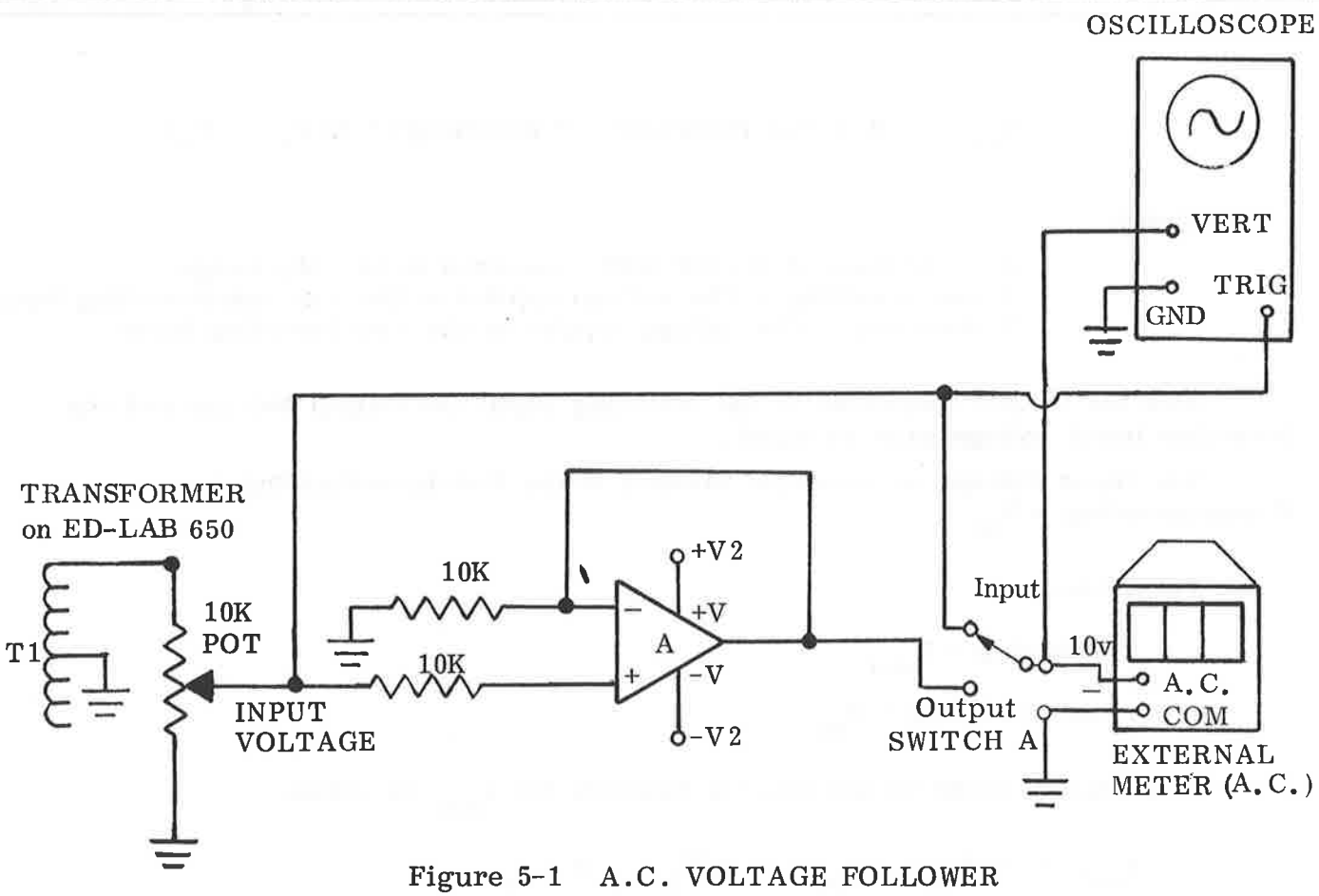


Figure 5-1 A.C. VOLTAGE FOLLOWER

OBJECTIVE:

You will measure the VOLTAGE GAIN for a NON-INVERTING UNITY FOLLOWER for A.C. Signal Inputs.

DESCRIPTION:

The A.C. voltage follower circuit of Figure 5-1 is the same as the VOLTAGE FOLLOWER circuit studied in Experiment No. 4. The difference is that the INPUT SIGNAL is an A.C. SINE WAVE generated by the Ed-Lab 650 Transformer and controlled by the 10K Potentiometer. The direct feedback from the OP-AMP Output to the Inverting input keeps the Voltage Gain at 1.

The Integrated Circuit Operational Amplifier on the Ed-Lab 650 is used.

ANALYSIS:

When analyzing an Operational Amplifier circuit the following assumptions are made:

1. The gain of the OP-AMP itself is very large.
2. The current into the + and - inputs is negligible.

In the circuit shown in Figure 2-1 the output of the OP-AMP is connected directly to the Inverting (-) input. As in all OP-AMP circuits the output voltage is given by:

$$V_{out} = A(V \text{ non-inverting} - V \text{ inverting}) = A(V_+ - V_-)$$

where:

A = The Gain of the OP-AMP - assumed to be Very Large
V non-inverting = The voltage applied to the + or non-inverting input
V inverting = The voltage applied to the - or Inverting input

With the Output connected to the Inverting Input the Output Voltage and the Inverting Input voltage must be equal.

The Input Voltage is connected directly to the Non-Inverting Input so V non-inverting = V_{in}

Therefore:

V inverting = V_{out}

V non-inverting = V_{in}

Substituting these values into the equation for V_{out} we obtain

$$V_{out} = A(V_{in} - V_{out}) = A\,V_{in} - A\,V_{out}$$

We can add $A\,V_{out}$ to both sides of the equation

$$V_{out} + A\,V_{out} = A\,V_{in}$$

$$V_{out}\,(1 + A) = A\,V_{in}$$

solving for the Gain we get

$$\frac{V_{out}}{V_{in}} = \text{GAIN} = \frac{A}{1+A}$$

if A = 10,000 then

$$\frac{V_{out}}{V_{in}} = \text{GAIN} = \frac{10,000}{10,000 + 1} = \frac{10,000}{10,001} = 1$$

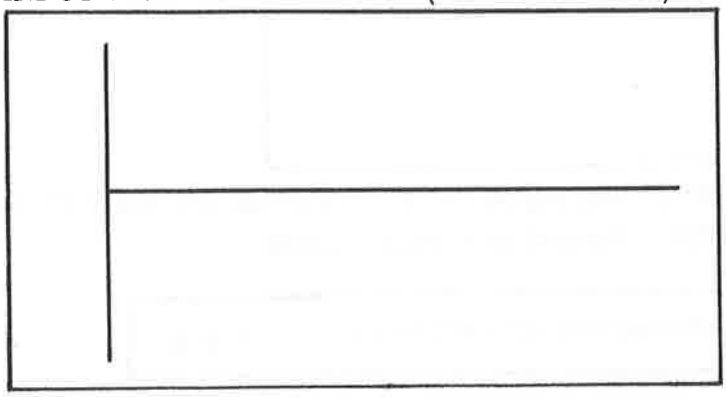
GAIN ≐ 1

Ed-Lab	A.C. VOLTAGE FOLLOWER	EXP. NO. 5 Page No. 3

PROCEDURE:

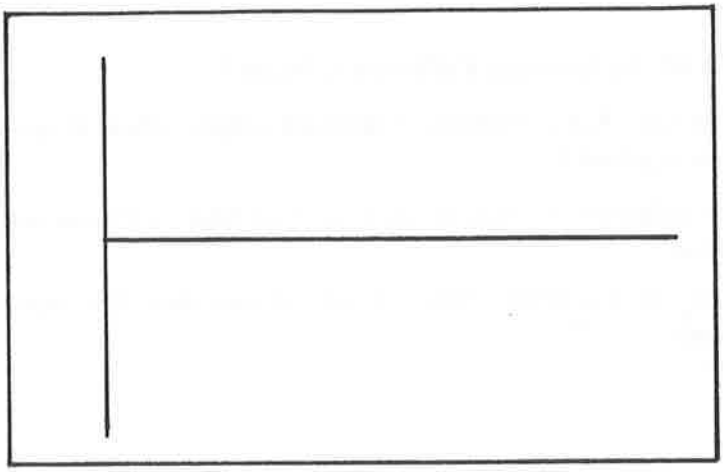
1. Wire the circuit shown in Figure 5-1.
2. Adjust the Input Signal viewed on the Oscilloscope (Switch A UP) to 4.0 volts peak to peak. Adjust the oscilloscope TRIGGER to trigger on the Positive going input cycle.
3. Sketch the Input Signal Waveform. Record the A.C. Meter reading for the Input Voltage.

INPUT SIGNAL WAVEFORM (SWITCH A UP)



A.C. VOLTS = _____ VRMS

4. Sketch the Output Waveform (SWITCH A DOWN) and Record the A.C. Meter reading for the Output Voltage



A.C. VOLTS = _____ VRMS

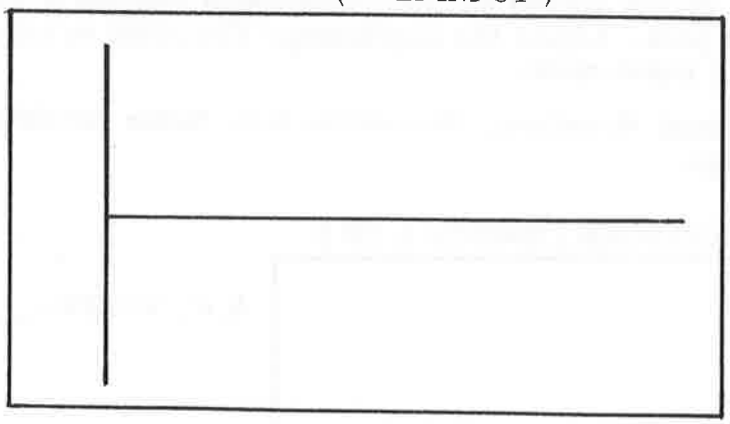
5. Calculate the VOLTAGE GAIN of the Amplifier

$$\text{Voltage Gain} = \frac{V_{out}}{V_{in}}$$

VOLTAGE GAIN =

6. Set the Input Voltage at MAXIMUM.
   Sketch the OUTPUT WAVEFORM

OUTPUT WAVEFORM (MAX INPUT)



7. Monitor the Output Voltage and adjust the Input Voltage for MAXIMUM UNDISTORTED OUTPUT. Record this Input Voltage

V_{in} (MAX UNDISTORTED OUTPUT) = v p-p

QUESTIONS:

1. What is the A.C. gain of the Voltage Follower Circuit?
2. What effect is noted at the A.C. Voltage Follower output when large A.C. input signals are applied?
3. Will the output of this follower circuit be In Phase or Out of Phase with with the input waveform?
4. What is the purpose of using a unity gain circuit? (Consider the input and output impedances)

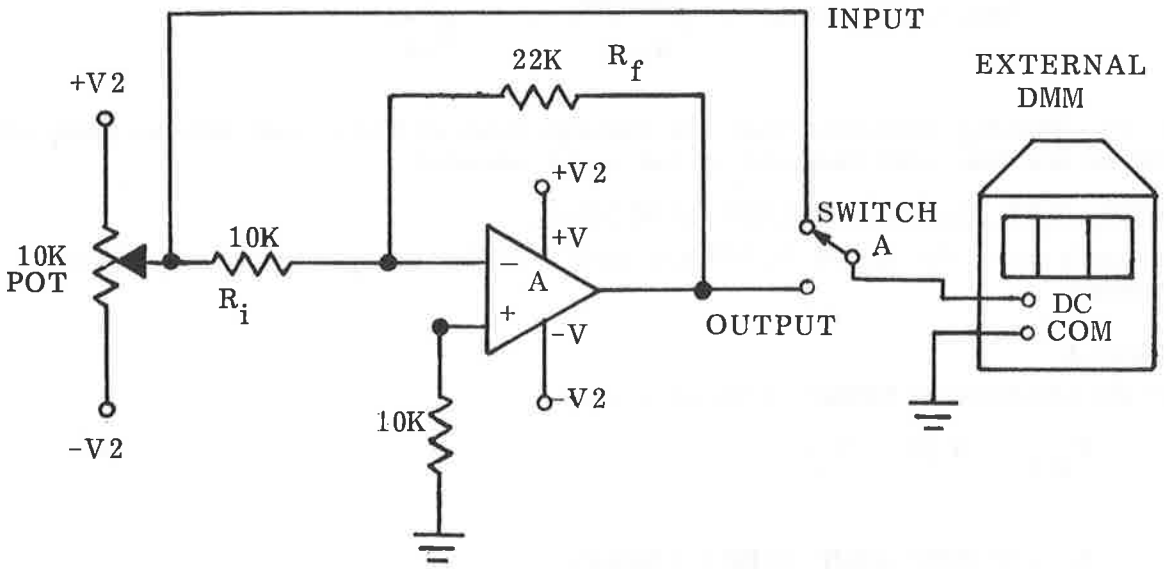


Figure 6-1 INVERTING AMPLIFIER

OBJECTIVE:

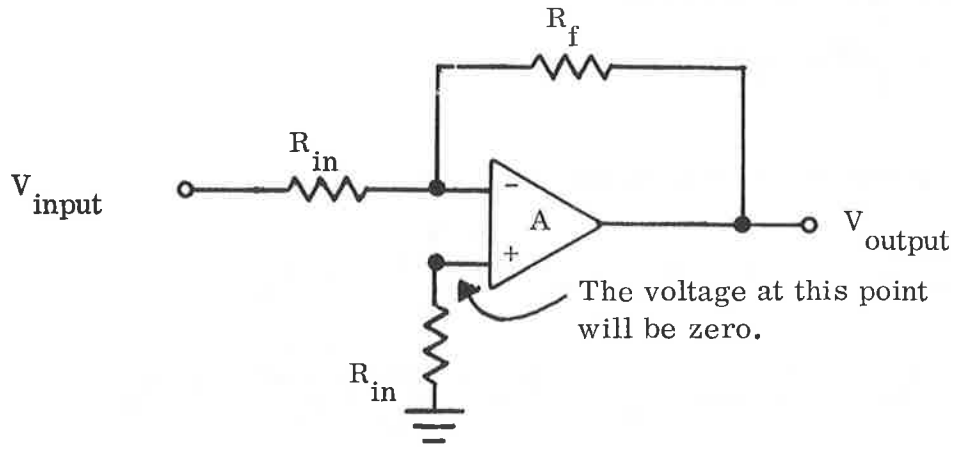
You will measure the VOLTAGE GAIN of an INVERTING AMPLIFIER for both D.C. and A.C. signal inputs.

DESCRIPTION:

The feedback resistor provides feedback from the OP-AMP output to the Inverting Input causing the Inverting Input to be equal in voltage to the non-inverting input. Since the Non-Inverting input is connected to ground, or zero volts, the feedback will act to make the Inverting Input equal to zero. Therefore, if the V_{in} is positive the V_{out} must be negative and the circuit will have negative gain.

The gain is given by

$$\text{GAIN} = -\frac{R_f}{R_{in}}$$



$$\text{VOLTAGE GAIN} = \frac{V_{output}}{V_{input}} = -\frac{R_f}{R_{in}}$$

This relationship indicates that the Voltage Gain of the circuit will be determined by the ratio of the feedback resistor to the input resistor.

THE STUDENT MAY SKIP OVER THIS ANALYSIS:

This analysis of the GAIN FORMULA uses a different approach from the one used previously.

GAIN FORMULA

For the Operational Amplifier we know that

$$V_{out} = A\,(V_+ - V_-)$$

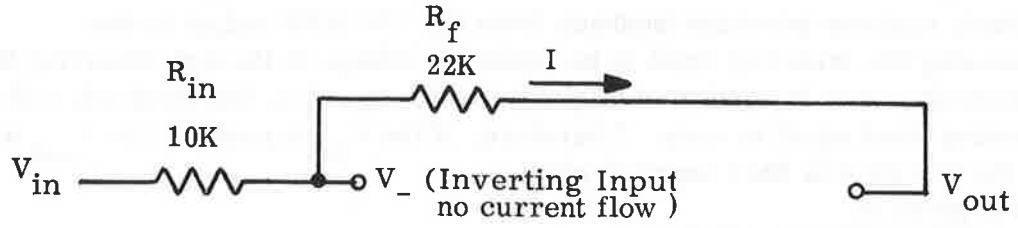
A = OP-AMP GAIN (VERY LARGE)

V_+ = Non-Inverting input voltage

V_- = Inverting input voltage

NOTE: The student may skip over this proof

Since we assume that the OP-AMP inputs do not draw any current we can use the Following equivalent circuit to calculate the voltage at the Inverting Input



The 10K input resistor and the 22K feedback resistor are connected in series and the V_- input voltage is the voltage appearing at the junction of the two resistors.

The current flowing in the Circuit is:

$$I = \frac{E}{R} = \frac{V_{out} - V_{in}}{R_{in} + R_f}$$

The voltage drop across the Input Resistor R_{in} is:

$$V_{across\ R_{in}} = I \times R_{in} = \frac{V_{out} - V_{in}}{R_{in} + R_f} \times R_{in}$$

$$V_- = V_{in} + V_{across\ R_{in}} = V_{in} + \frac{V_{out} - V_{in}}{R_{in} + R_f} \times R_{in}$$

Putting this value into the basic equation for the V_{out} of an OP-AMP we obtain:

$$V_{out} = A\left[V_{+} - \left(V_{in} + \frac{V_{out} - V_{in}}{R_{in} + R_f} \times R_{in}\right)\right]$$

since V_{+} is connected to ground, $V_{+} = 0$

$$V_{out} = -A\left(V_{in} + \frac{V_{out} - V_{in}}{R_{in} + R_f} \times R_{in}\right)$$

if we divide both sides by A then

$$\frac{V_{out}}{A} = -V_{in} - \frac{V_{out} - V_{in}}{R_{in} + R_f} \times R_{in}$$

since A = large $\frac{V_{out}}{A} = 0$ and

$$-V_{in} = +\frac{V_{out} - V_{in}}{R_{in} + R_f} \times R_{in}$$

$$-V_{in} + \frac{V_{in} R_{in}}{R_{in} + R_f} = \frac{V_{out} R_{in}}{R_{in} + R_f}$$

$$V_{in}\left[\frac{R_{in}}{R_f + R_{in}} - 1\right] = \frac{V_{out}}{R_f + R_{in}} R_{in}$$

$$\frac{V_{out}}{V_{in}} = \left[\frac{R_{in}}{R_f + R_{in}} - 1\right] \frac{R_f + R_{in}}{R_{in}} = \frac{R_{in} - R_f + R_{in}}{R_{in}} = -\frac{R_f}{R_{in}}$$

$$\boxed{\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}} = \text{GAIN}}$$

PROCEDURE:

1. Wire the circuit shown in Figure 6-1.
2. Use switch A to monitor either the INPUT VOLTAGE (SWITCH A UP) or the OUTPUT VOLTAGE (SWITCH A DOWN).
3. With Switch A UP, adjust the INPUT VOLTAGE to the levels indicated in Table A.
4. With Switch A DOWN, measure the OUTPUT VOLTAGE and record the results in Table A.
   Note: The INPUT VOLTAGE and the OUTPUT VOLTAGE will be opposite in polarity. Reverse the Meter leads if necessary to read the voltage.

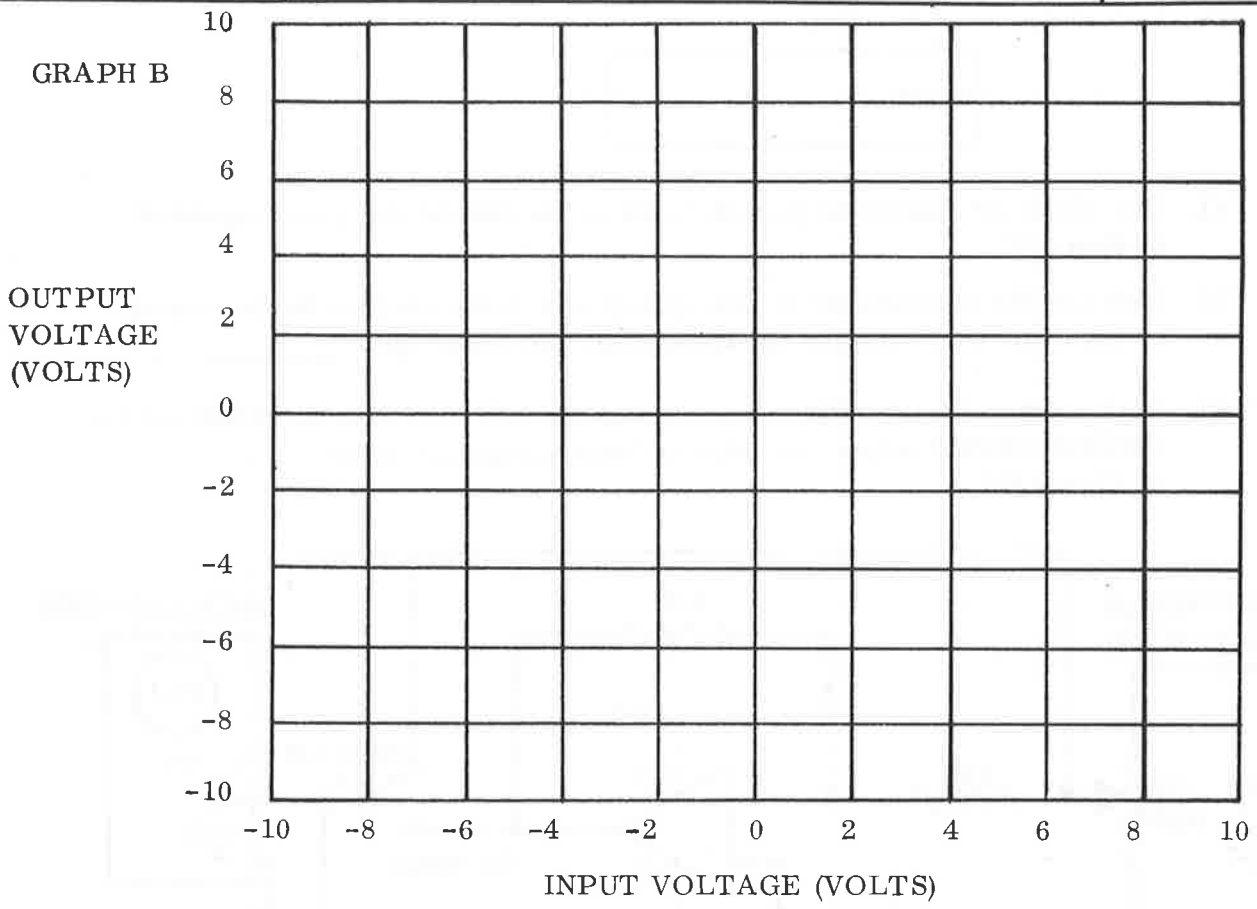
TABLE A

INPUT VOLTAGE (VOLTS) SWITCH A UP SET WITH 10K POT	OUTPUT VOLTAGE (VOLTS) SWITCH A DOWN RECORD VOLTAGE AND POLARITY
+9	
+8	
+7	
+6	
+3	
+1	
0	
-1	
-3	
-6	
-7	
-8	
-9	

5. Plot the Data from Table A on the GRAPH B. Label the curve D.C. GAIN.

Ed-Lab | INVERTING AMPLIFIER | **EXP. NO.** 6 **Page No.** 5

GRAPH B



6. For Zero Volts Input does the circuit Output Voltage equal Zero?_____

7. Calculate the VOLTAGE GAIN for an Input Voltage of +2 volts

$$\text{VOLTAGE GAIN (+2 volts input)} = \frac{V_{out}}{V_{in}} = \text{_____} =$$

VOLTAGE GAIN =

8. Calculate the VOLTAGE GAIN for an Input Voltage of -2.0 volts

$$\text{VOLTAGE GAIN (-2.0 volts input)} = \frac{V_{out}}{V_{in}} = \text{_____}$$

VOLTAGE GAIN =

9. Are the VOLTAGE GAIN values calculated in 7 and 8 Positive or Negative?_____

10. Calculate the Theoretical Value of the Voltage Gain for the Inverting Amplifier.

$$\text{GAIN} = -\frac{R_f}{R_{in}} = -\frac{22K}{10K} =$$

GAIN =

11. How does the measured gain compare to the theoretical gain calculated in step 10?

12. Which of the components in this system are most likely to be the source of any difference between the theoretical and actual gain?_____.

13. Replace the +V2 and -V2 connections to the 10K POT with GROUND and the TRANSFORMER output and add the Oscilloscope as shown in Figure 6-2.

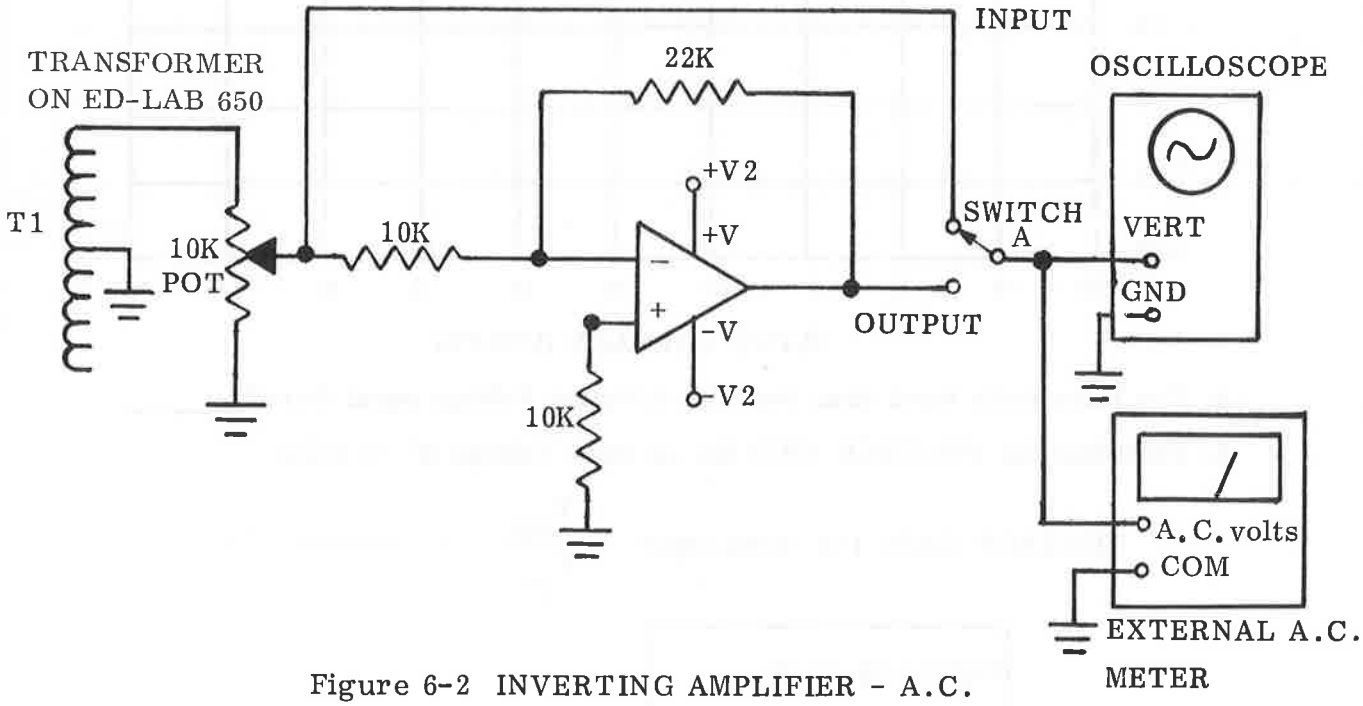


Figure 6-2 INVERTING AMPLIFIER - A.C.

DESCRIPTION:

An A.C. signal is applied to the Input of the INVERTING AMPLIFIER and the A.C. Input and Output Signals are monitored on an Oscilloscope. The INVERTING AMPLIFIER will have the same gain for this A.C. signal as it had for the D.C. Input signal.

PROCEDURE:

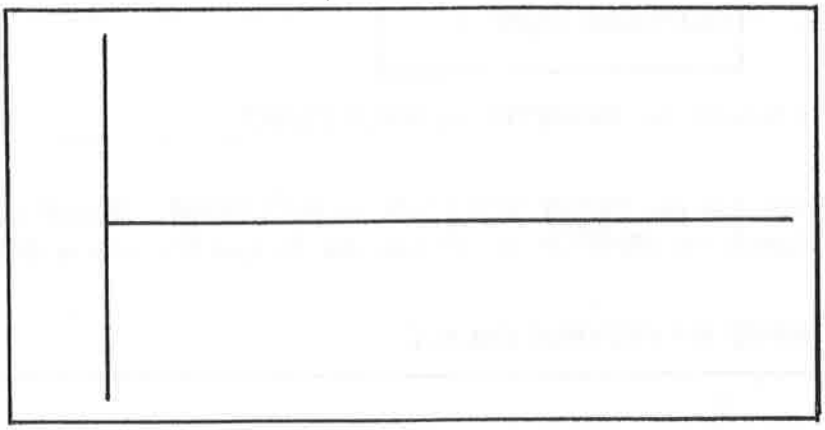
1. Wire the circuit shown in Figure 6-2.

2. Adjust the INPUT VOLTAGE (SWITCH A UP) using the 10K POT to the levels indicated (use the Oscilloscope or the External A.C. meter).

3. Set the INPUT VOLTAGE to 2 volts Peak to Peak

4. Sketch the Input Waveform (SWITCH A UP), record the A.C. Meter reading

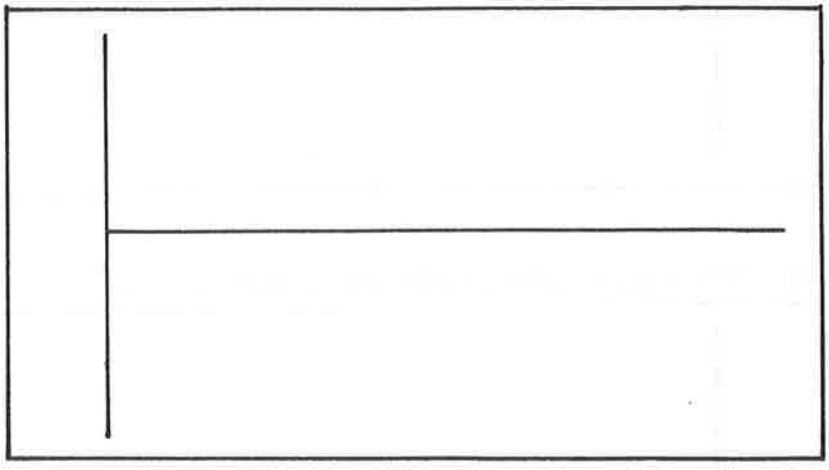
INPUT WAVEFORM (2.0 volts Peak to Peak)



A.C. Volts (RMS) = _____

5. Monitor the Output Waveform (SWITCH A DOWN). DO NOT CHANGE THE SETTING OF THE 10K POT. Sketch the Output Waveform, record the A.C. Meter reading.

OUTPUT WAVEFORM



A.C. Volts (RMS) = _____

6. If a dual trace oscilloscope is available monitor the input voltage and the output voltage simultaneously. Are they in phase?_____

7. Calculate the VOLTAGE GAIN

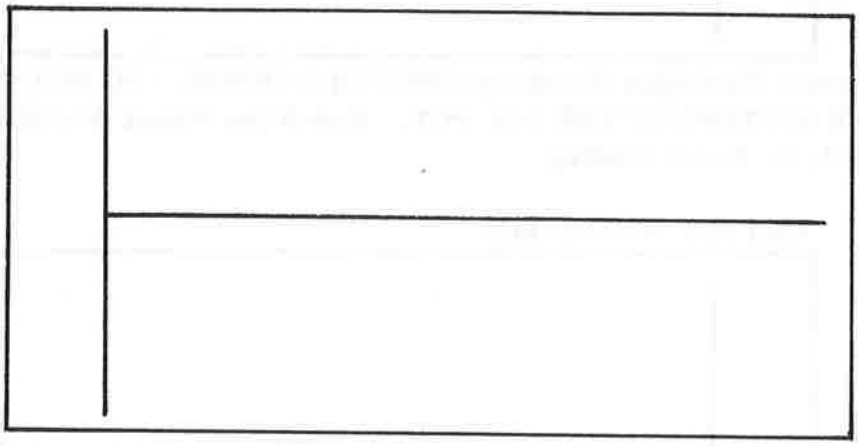
$$\text{VOLTAGE GAIN} = \frac{V_{out}}{V_{in}} = _____$$

VOLTAGE GAIN =

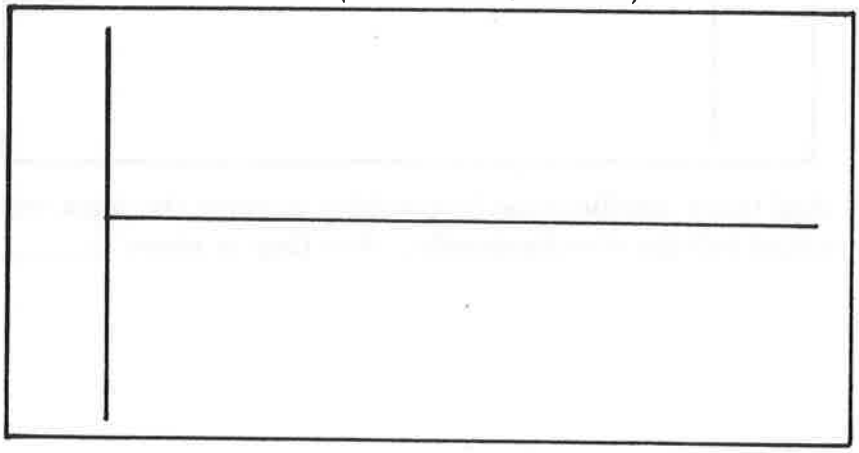
Is this Gain POSITIVE or NEGATIVE?_____

8. Increase the INPUT VOLTAGE to MAXIMUM. Sketch the Input Waveform (SWITCH A UP) and the Output Waveform (SWITCH A DOWN).

INPUT WAVEFORM (MAX.)



OUTPUT WAVEFORM (WITH MAX. INPUT)



Is this circuit a good Linear Amplifier for very large input voltages?_____

9. Reduce the Input Voltage Amplitude while observing the Output Waveform on the Oscilloscope. Set the Input Voltage (10K POT) at the maximum level which results in an UNDISTORTED OUTPUT SIGNAL.

10. Record the MAXIMUM INPUT SIGNAL AMPLITUDE for UNDISTORTED OUTPUT.

V_{in} (MAX) =

INPUT IMPEDANCE:

The Input Impedance of the Inverting Amplifier circuit is equal to the value of R_{in}. We will check this using the procedure below.

PROCEDURE:

1. Set V_{in} at 2 volts peak to peak (SWITCH A UP)

2. Record the V_{output} peak to peak (SWITCH A DOWN)

V_{output} = volts peak to peak

3. Add a 10K input resistor as shown in Figure 6-3.

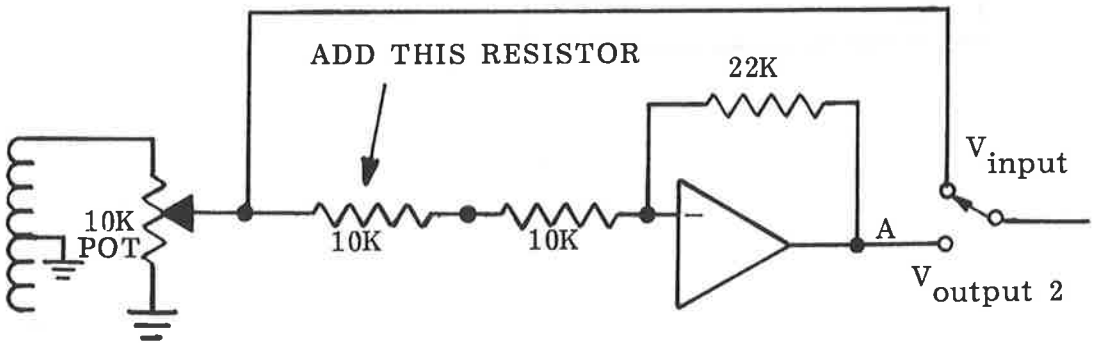


Figure 6-3 INPUT IMPEDANCE

4. Check that the Input Voltage is still 2 volts peak to peak (SWITCH A UP)

5. Record the V_{output} (with 10K) (SWITCH A DOWN)

V_{output} (with 10K) = volts peak to peak

6. Calculate the Input Impedance

$$\frac{V_{output} \text{ (with 10K)}}{V_{output}} = \frac{R_{in}}{R_{in} + 10K}$$

$$V_{output} \text{ (with 10K)} \left[R_{in} + 10K\right] = R_{in} \left(V_{output}\right)$$

$$R_{in} = \frac{+V_{output} \text{ (with 10K)} \times 10K}{V_{output} - V_{output} \text{ (with 10K)}} = _____$$

$$R_{in} = \frac{(\quad) \times 10K}{(\quad) - (\quad)} = _____$$

R_{in} = ohms

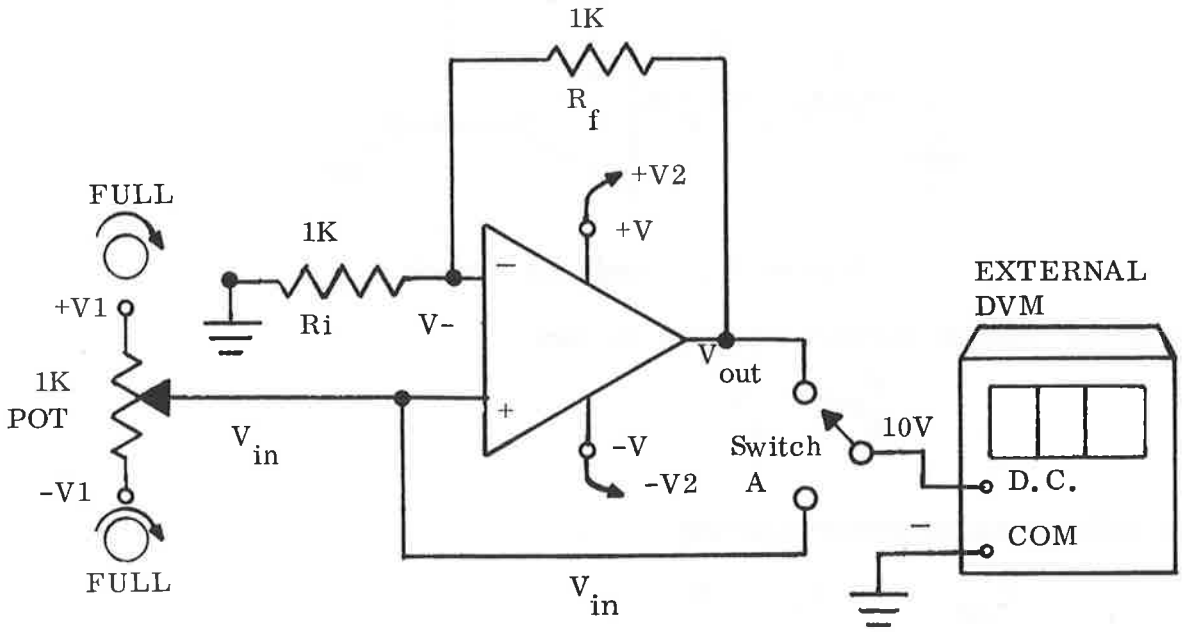


Figure 7-1 POSITIVE GAIN CIRCUIT

OBJECTIVE:

You will test the operation of a positive gain OP-AMP circuit and measure the gain.

DESCRIPTION:

The circuit in Figure 7-1 above is similar to that of the Voltage Follower except that it has a positive voltage gain given by the feedback resistance circuit. The Gain in this circuit is 2 and is derived later in this experiment. The advantage of this circuit is that the input impedance is very high as in the voltage follower circuit.

ANALYSIS:

The gain for the circuit shown in Figure 7-1 is given by the following analysis.

The circuit shown in figure 7-1 is very similar to the Voltage Follower circuit. The Input Voltage is applied directly to the Non-Inverting Input of the Operational Amplifier. The Feedback path is through the Voltage Divider circuit formed by the R_f and R_i resistors connected in series. If we assume that the Operational Amplifier Input is a very high impedance and draws no current then the feedback circuit can be drawn as shown in figure 7-2.

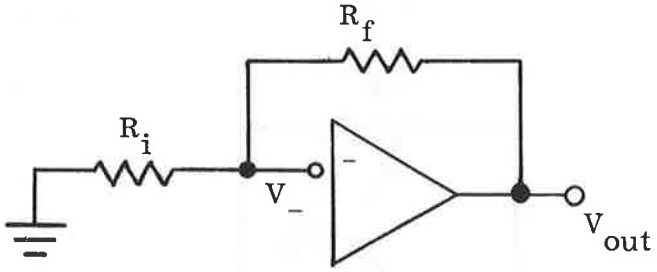


Figure 7-2 Feedback Circuit

Using the Voltage Divider Equation we see:

$$V_- = \frac{V_{out} \times R_i}{R_i + R_f}$$

The differential amplifier equation:

$$V_{out} = A(V_+ - V_-)$$

$$V_+ = V_{in}$$

When we substitute the values for V_+ and V_- into this equation we get:

$$V_{out} = A\left[V_{in} - \frac{V_{out}(R_i)}{R_i + R_f}\right]$$

We can divide both sides of the equation by A:

$$\frac{V_{out}}{A} = V_{in} - \frac{V_{out}(R_i)}{R_i + R_f}$$

If A is very large then $\frac{V_{out}}{A} = 0$ and

$$0 = V_{in} - \frac{V_{out}(R_i)}{R_i + R_f}$$

$$V_{in} = \frac{V_{out}(R_i)}{R_i + R_f}$$

$$\boxed{\frac{V_{out}}{V_{in}} = \frac{R_i + R_f}{R_i} = \text{GAIN}}$$

$$\text{GAIN} = \frac{R_i + R_f}{R_i}$$

for the values of R_i and R_f given in the schematic

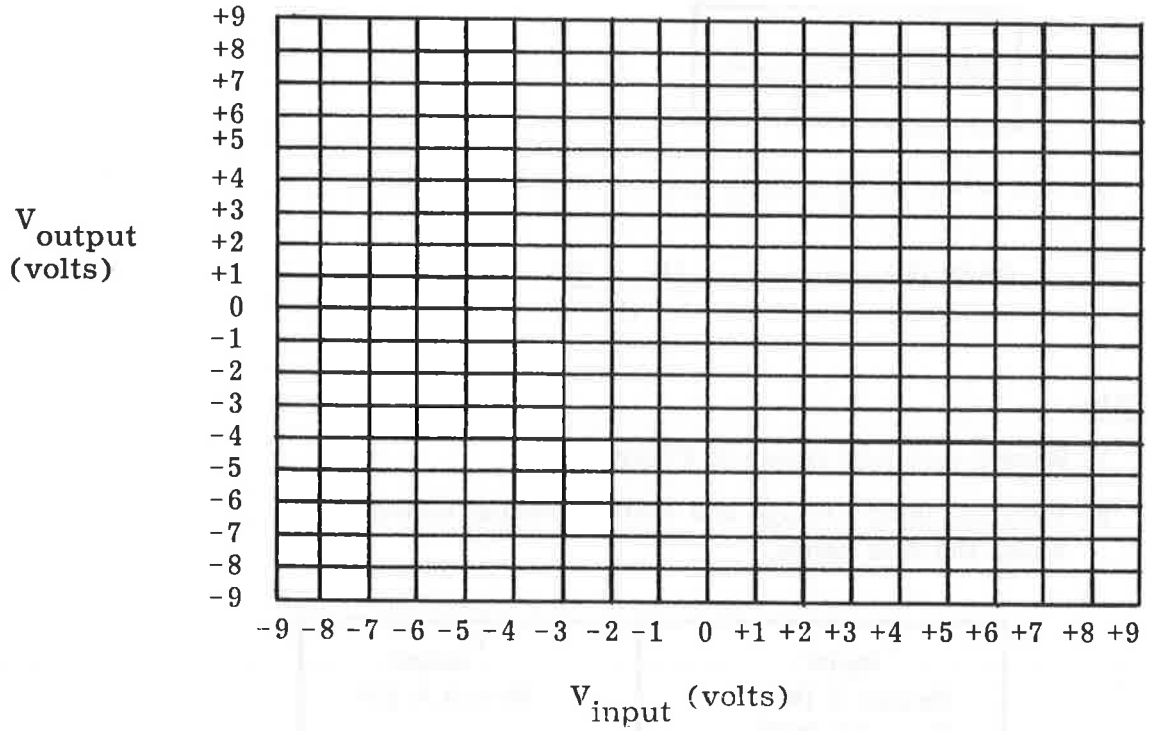
$$\text{GAIN (Experiment)} = \frac{1K + 1K}{1K} = 2$$

PROCEDURE:

1. Wire the circuit shown in Figure 7-1
2. Vary the input Voltage and read the output voltage. Enter the data below.

V_{input} Switch A DOWN Vary 1K POT	V_{output} Switch A UP
0.0	
0.5	
1.0	
1.5	
2.0	
2.5	
3.0	
3.5	
4.0	
6.0	
8.0	
-0.5	
-1.0	
-1.5	
-2.0	
-2.5	
-3.0	
-3.5	
-4.0	
-6.0	
-8.0	

3. Plot the results in the graph below:



4. Observe that there is a definite linear operating range for this circuit.

5. Calculate the gain which is the slope of the curve. Select 2 points to determine the slope:

$$\text{Gain} = \frac{\Delta V_{out}}{\Delta V_{in}} = \text{_____}$$

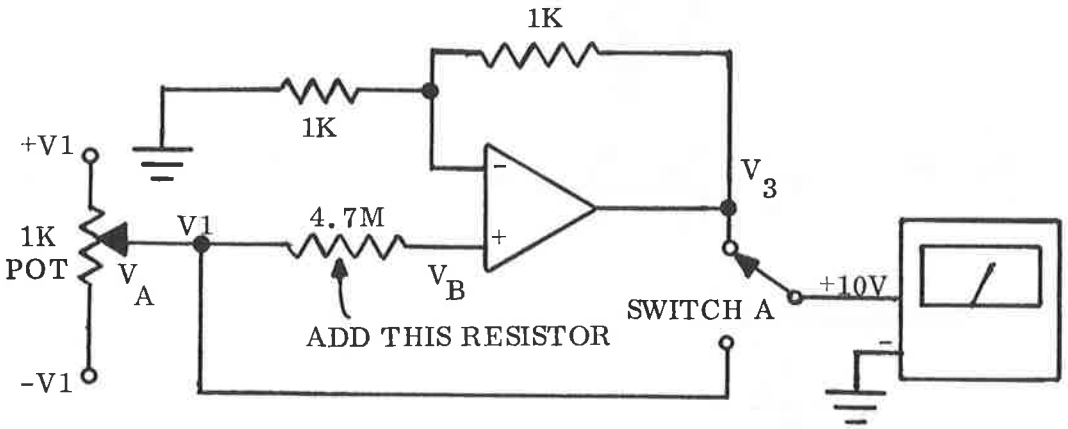
MEASURED GAIN =

6. How does the above measured gain compare with the calculated gain of 2?

7. Input Impedance Measurement
With Switch A DOWN set the Input Voltage to 2 volts. Place Switch A UP and record the Output Voltage V_B below.

V_B = volts

Modify the circuit by connecting a 4.7 Megohm Resistor in series with the input + terminal as shown below:



8. With Switch A DOWN make sure the input voltage is still 2 volts

9. Place SWITCH A UP to measure the new Output Voltage V_3 and record below:

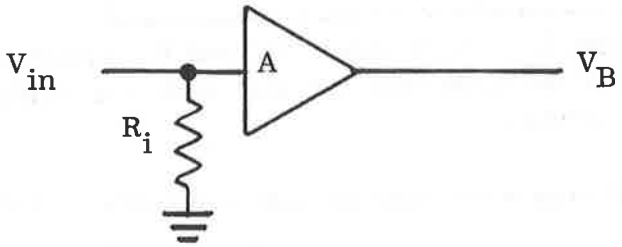
V_3 =

10. Calculate the Input Impedance using the following equations

$$R_{in} = 4.7M \left(\frac{V_3}{V_B - V_3} \right) = 4.7M \left[\frac{(\quad)}{(\quad) - (\quad)} \right]$$

R_{in} = ohms

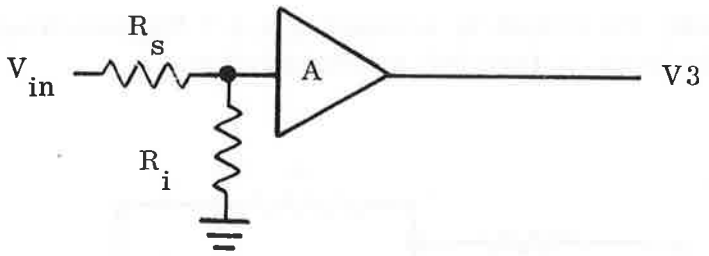
11. The formula for Input Impedance is derived below:



Eq. (1) $V_B = A\ V_{in}$

A = Gain

R_i = Amplifier Input Impedance



Eq. (2) $$V_3 = \frac{V_{in} \; R_i}{R_i + R_s} \times A$$

from equation (1)

$$A = \frac{V_B}{V_{in}}$$

by substituting this in equation (2) we see

$$V_3 = \frac{V_{in} \; R_i}{R_i + R_s} \times \frac{V_B}{V_{in}} = \frac{R_i \times V_B}{R_i + R_s}$$

$$V_3 \; (R_i + R_s) = V_B \; R_i$$

$$V_3 \; (R_s) = R_i \; (V_B - V_3)$$

$$R_i = \frac{V_3 \; (R_s)}{V_B - V_3} = \text{Input Impedance}$$

in this experiment R_s = 4.7M ohms, V_B and V_3 are the output voltage measured without the 4.7M resistor and with the 4.7M resistor for a 2 volt input setting.

12. Is the Input Impedance High or Low compared to 10K?

QUESTIONS:

1. What gain would result from the use of R_f = 10K and R_i = 1K?
2. What resistors would you use to result in a gain of 3?
3. What resistors would you use to result in a gain of 100?
4. What is the "phase" of the output with respect to the input; in phase or out-of-phase ?
5. Is this circuit a "buffer amplifier"?
6. How would you measure the input impedance?
7. How would you measure the output impedance of this circuit?

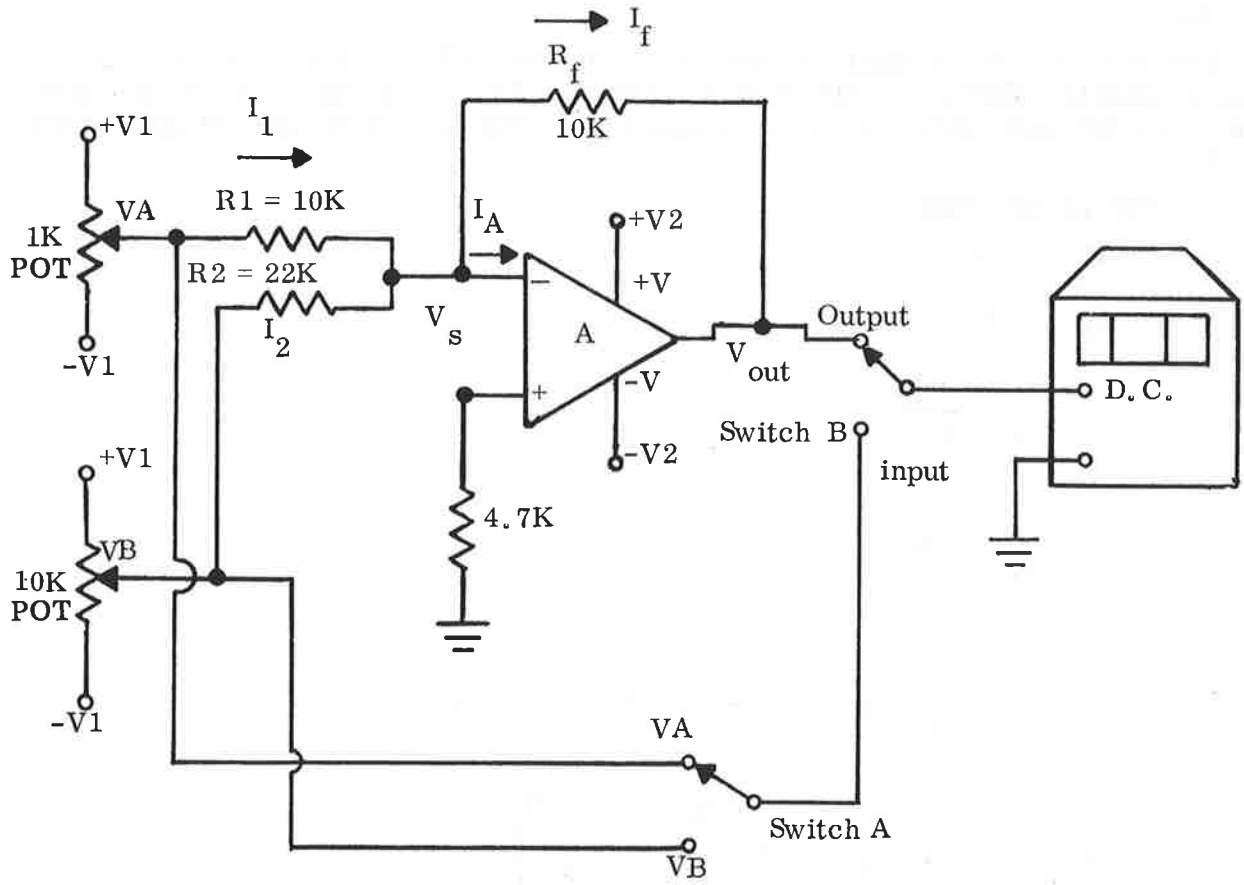


Figure 8-1 SUMMING AMPLIFIER

OBJECTIVE:

To use the Operational Amplifier as a SUMMER to generate an Output Voltage equal to the SUM of two independent Input Voltages.

DESCRIPTION:

The SUMMER is an Inverting Amplifier with two Independent input voltages applied to two Input Resistors connected to the INVERTING INPUT. The circuit is shown in Figure 8-1.

The Output Voltage is proportional to the SUM of the two Input Voltages.

The formula for the Output Voltage is given below:

$$V_{out} = - \left[V_A \frac{R_f}{R_1} + V_B \frac{R_f}{R_2} \right]$$

The Output Voltage is Negative for Positive Input Voltages and is proportional to the Sum of the Input Voltages.

ANALYSIS:

The Non-Inverting input is connected to GROUND via the 4.7K resistor. The feedback Resistor allows the OP-AMP to keep the Inverting input at Ground also. As in the other OP-AMP circuits, it is assumed that the Inputs to the OP-AMP draw no current.

For an OP-AMP

$V_s = 0$

$I_A = 0$

$$I_1 = \frac{V_A}{R_1}$$

$$I_2 = \frac{V_B}{R_2}$$

$$I_f = I_1 + I_2 = \frac{V_A}{R_1} + \frac{V_B}{R_2}$$

$$V_{out} = -R_f I_f = -R_f \left(\frac{V_A}{R_1} + \frac{V_B}{R_2} \right)$$

$$V_{out} = \frac{-R_f}{R_1} V_A - \frac{R_f}{R_2} V_B = -R_f \left[\frac{V_A}{R_1} + \frac{V_B}{R_2} \right]$$

This equation shows that the Output Voltage is proportional to V_1 and V_2. If $R_f = R_1 = R_2$ then

$$V_{out} = -V_A - V_B = -(V_A + V_B)$$

PROCEDURE:

1. Wire the circuit shown in Figure 8-1
2. Place Switch B DOWN to monitor the Input Voltage. Set VA (SWITCH A UP, 1K POT) and VB (SWITCH A DOWN, 10K POT) to the values shown in the Data Table.
3. Place SWITCH B UP and Record the Output Voltage in the Table

V_A	V_B	Measured V_{output}	Calculated V_{output}
1.0	0		
0	1.0		
1.0	1.0		
2.0	1.0		
3.0	0.5		
-1.0	+1.0		
1.0	-1.0		
2.0	-4.0		

4. Calculate the Theoretical Value of V_{output} for each set of Input Voltages using the formula below:

$$V_{output} = -R_f\left[\frac{V_A}{R_1} + \frac{V_B}{R_2}\right] = -10K\left[\frac{V_A}{10K} + \frac{V_B}{22K}\right]$$

$$V_{output} = -\left[V_A + \frac{1}{2.2} V_B\right]$$

Enter the Calculated V_{out} in the Table of step 3.

5. Change R_2 from 22K to 10K. Now $R_f = R_1 = R_2$

6. Place Switch B DOWN, Set V_A and V_B to the values given in the Table on the following page.

7. Place SWITCH B UP, Record the V_{output} for each set of input voltages.

V_A	V_B	MEASURED V_{output}	CALCULATED V_{output}
0	0		
1.0	0		
0	1.0		
1.0	1.0		
2.0	2.0		
-1.0	0		
0	-1.0		
-2.0	-2.0		

8. Calculate the Theoretical Value of V_{output} using the formula below

$$V_{output} = -\left(V_A + V_B\right)$$

9. Do the Measured $V_{outputs}$ and the Calculated $V_{outputs}$ agree?

10. Why is there any difference between the calculated and the measured V_{output}?

11. Will this circuit work for A.C. Input Voltages?

QUESTIONS:

1. Can this circuit be used to sum more than two voltages.
2. Draw the circuit used to sum 4 input voltages.

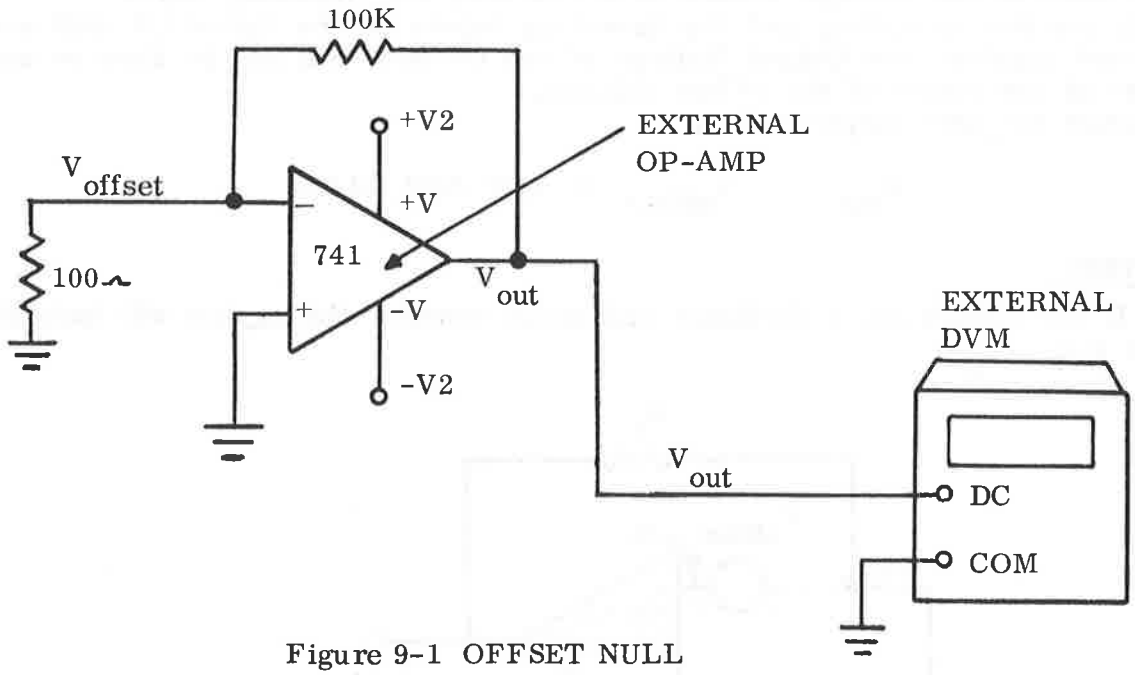


Figure 9-1 OFFSET NULL

OBJECTIVE:

The student will measure the OFFSET voltage of an external operational amplifier. He will then Null this offset voltage.

DESCRIPTION:

Operational Amplifiers have a characteristic called Offset Voltage. The Offset Voltage is given in the data sheets for each type of Operational Amplifier. The typical value for an Integrated Circuit Operational Amplifier is between 10 millivolts and 2 millivolts.

The Offset Voltage is a property of the components inside the Integrated Circuit. It's effect is the same as a voltage in series with the Inverting Input of the Operational amplifiers.

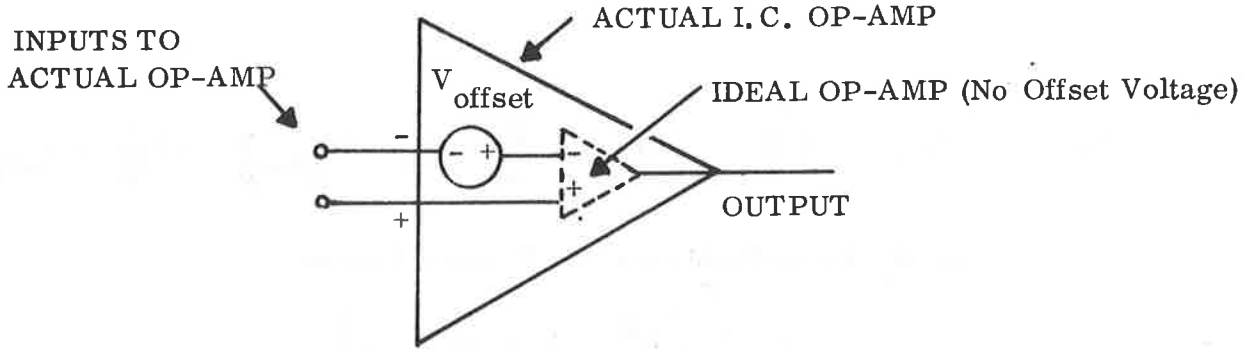


Figure 9-2 Model of OP-AMP Showing OFFSET VOLTAGE

Figure 9-2 shows a model of the Practical Operational Amplifier as an Ideal OP-AMP with a small Offset Voltage Source in series with the Inverting Input.
If both the Non-Inverting and the Inverting inputs to the Actual OP-AMP are connected together the Output Voltage of the OP-AMP will not be Zero as expected because of the effect of the Offset Voltage.
The actual OP-AMP output will be:

$$V_{out} = -V_{offset} \times (\text{OP-AMP GAIN})$$

ANALYSIS:

If the circuit has a feedback and input resistor the system will look like that in Figure 9-3.

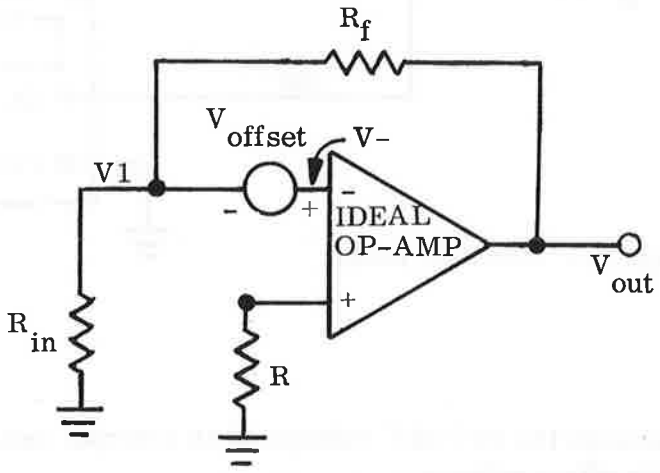


Figure 9-3 OP-AMP CIRCUIT WITH OFFSET VOLTAGE

Eq. 1 $$V_1 = \frac{V_{out}(R_{in})}{R_{in} + R_f}$$

Eq. 2 $$V_- = V_1 + V_{offset}$$

Eq. 3 $$V_{out} = A\left(V_+ - V_-\right) = A\left(0 - V_1 - V_{offset}\right) = -A\left(V_1 + V_{offset}\right)$$

when we substitute Equation 1 into Equation 3 we see

$$V_{out} = -A\left[\frac{V_{out}\, R_{in}}{R_{in} + R_f} + V_{offset}\right]$$

$$V_{out}\left[1 + \frac{A\ R_{in}}{R_{in} + R_f}\right] = -A\ V_{offset}$$

$$V_{out} = \frac{-A\ V_{offset}}{1 + \frac{A\ R_{in}}{R_{in} + R_f}} = \frac{-V_{offset}}{\frac{1}{A} + \frac{R_{in}}{R_f + R_{in}}}$$

As A becomes very large $\frac{1}{A}$ becomes negligable and

$$V_{out} = \frac{-V_{offset}\ (R_f + R_{in})}{R_{in}}$$

Note that the Output Voltage caused by the Offset Voltage will be large when R_f is much greater than R_{in}. This means that for high gain OP-AMP circuits ($R_f >> R_{in}$) the OP-AMP output will be greatly effected by the Offset voltage
There are two methods of eliminating the offset voltage

a) An adjustable voltage can be added to the Inverting Input

b) Certain OP-AMP's have provision for Offset Null.

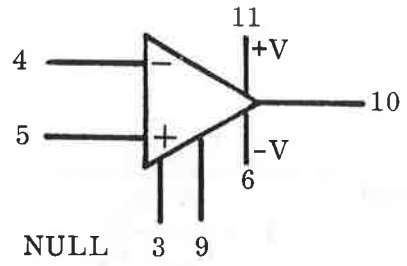
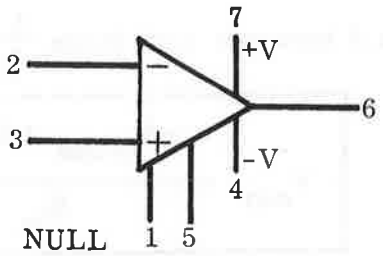
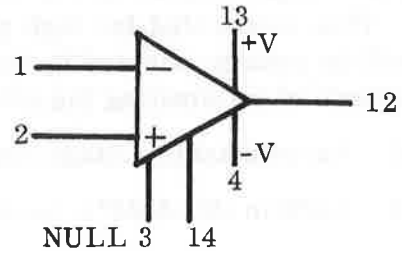
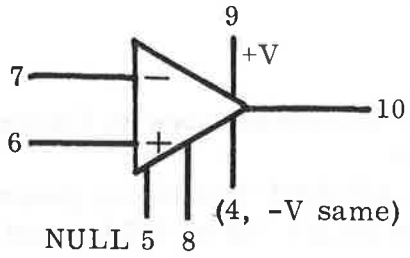
The effects of Offset voltage and the process of nulling this offset will be studied in this experiment.

PROCEDURE:

1. This experiment uses an External OP-AMP placed in the I.C. socket on the Ed-Lab 650.

The OP-AMP may be any general purpose OP-AMP but it is recommended that the µA 741 or 747 be used.

The 741 comes in 3 types of Packages. The pin connections are summarized below.

14 PIN DIP 741	
8 PIN DIP 741	
14 PIN DIP TWO 741 (Model NO. 747)	 

The specification sheets for the 741 and 747 OP-AMPs are given on the following two pages.

μA741

FREQUENCY-COMPENSATED OPERATIONAL AMPLIFIER

LINEAR INTEGRATED CIRCUITS

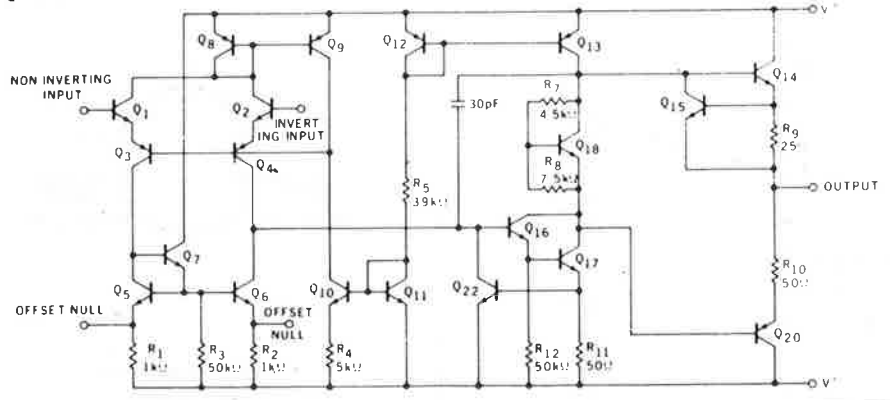
GENERAL DESCRIPTION - The μA741 is a high performance monolithic operational amplifier constructed on a single silicon chip, using the Fairchild Planar* epitaxial process. It is intended for a wide range of analog applications. High common mode voltage range and absence of "latch-up" tendencies make the μA741 ideal for use as a voltage follower. The high gain and wide range of operating voltage provides superior performance in integrator, summing amplifier, and general feedback applications.

- **NO FREQUENCY COMPENSATION REQUIRED**
- **SHORT-CIRCUIT PROTECTION**
- **OFFSET VOLTAGE NULL CAPABILITY**
- **LARGE COMMON-MODE AND DIFFERENTIAL VOLTAGE RANGES**
- **LOW POWER CONSUMPTION**
- **NO LATCH UP**

ABSOLUTE MAXIMUM RATINGS

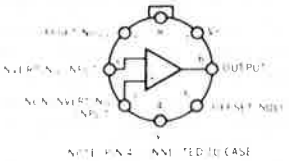
Supply Voltage	
Military (312 Grade)	±22 V
Commercial (393 Grade)	±18 V
Internal Power Dissipation (Note 1)	
Metal Can	500 mW
Ceramic DIP	670 mW
Silicone DIP	340 mW
Mini DIP	310 mW
Flatpak	570 mW
Differential Input Voltage	±30 V
Input Voltage (Note 2)	±15 V
Storage Temperature Range	
Metal Can, Ceramic DIP, and Flatpak	−65° C to +150° C
Mini DIP and Silicon DIP	−55° C to +125° C
Operating Temperature Range	
Military (312 Grade)	−55° C to +125° C
Commercial (393 Grade)	0° C to + 70° C
Lead Temperature (Soldering)	
Metal Can, Ceramic DIP and Flatpak (60 seconds)	300° C
Mini DIP and Silicone DIP (10 seconds)	260° C
Output Short Circuit Duration (Note 3)	Indefinite

EQUIVALENT CIRCUIT



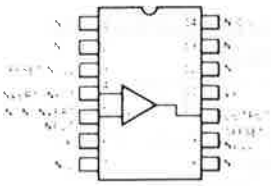
CONNECTION DIAGRAMS
(TOP VIEW)

8 LEAD METAL CAN



ORDER PART NOS.
U5B7741312
U5B7741393

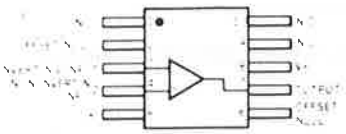
14 LEAD DIP



FOR CERAMIC DIP ORDER PART NOS.
U6A7741312
U6A7741393

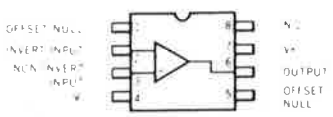
FOR SILICONE DIP ORDER PART NO.
U9A7741393

FLATPACK



ORDER PART NO.
U3F7741312

MINIDIP



ORDER PART NO.
U9T7741393

*Planar is a patented Fairchild process.

μA747

DUAL FREQUENCY COMPENSATED OPERATIONAL AMPLIFIER

LINEAR INTEGRATED CIRCUITS

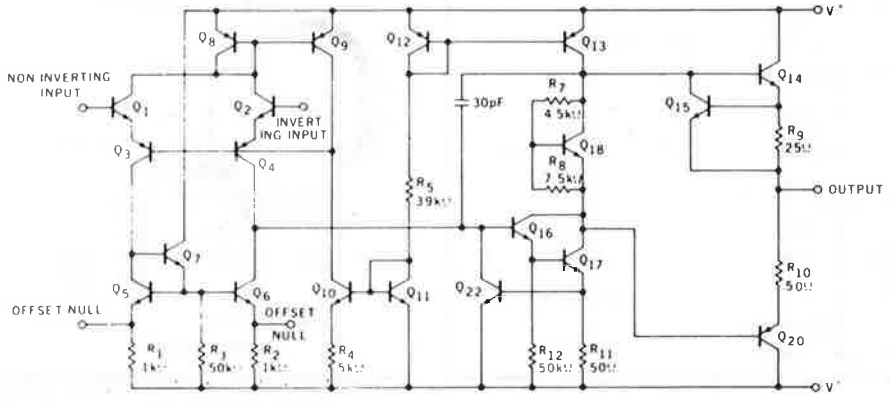
GENERAL DESCRIPTION — The μA747 is a pair of high performance monolithic operational amplifiers constructed on a single silicon chip, using the Fairchild Planar* epitaxial process. They are intended for a wide range of analog applications where board space or weight are important. High common mode voltage range and absence of "latch-up" make the μA747 ideal for use as a voltage follower. The high gain and wide range of operating voltage provides superior performance in integrator, summing amplifier, and general feedback applications. The μA747 is short-circuit protected and requires no external components for frequency compensation. The internal 6 dB/octave roll-off insures stability in closed loop applications. For single amplifier performance, see μA741 data sheet.

- **NO FREQUENCY COMPENSATION REQUIRED**
- **SHORT-CIRCUIT PROTECTION**
- **OFFSET VOLTAGE NULL CAPABILITY**
- **LARGE COMMON-MODE AND DIFFERENTIAL VOLTAGE RANGES**
- **LOW POWER CONSUMPTION**
- **NO LATCH UP**

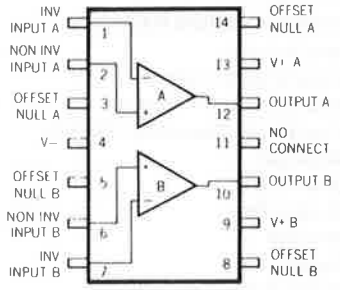
ABSOLUTE MAXIMUM RATINGS

Supply Voltage	
Military (312 Grade)	±22 V
Commercial (393 Grade)	±18 V
Internal Power Dissipation (Note 1)	
Metal Can	500 mW
Ceramic DIP	670 mW
Differential Input Voltage	±30 V
Input Voltage (Note 2)	±15 V
Voltage between Offset Null and V⁻	±0.5 V
Storage Temperature Range	−65°C to +150°C
Operating Temperature Range	−55°C to +125°C
Lead Temperature (Soldering, 60 seconds)	300°C
Output Short-Circuit Duration (Note 3)	Indefinite

EQUIVALENT CIRCUIT (Each Side)

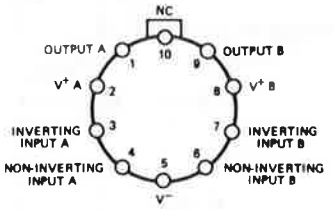


CONNECTION DIAGRAMS
(TOP VIEWS)
14 LEAD DIP



ORDER PART NOS.
U7A7747312
U7A7747393

10 LEAD METAL CAN



ORDER PART NOS.
U5F7747312
U5F7747393

*Planar is a patented Fairchild process.

2. Connect the Circuit shown in Figure 9-1.

3. Record the Output Voltage Below

V_{out} = volts

4. Calculate the Offset Voltage of the chip under test using the formula

$$V_{offset} = \frac{V_{out}\ (R_{in})}{R_f + R_{in}} = \frac{V_{out}\ (100)}{100 + 100,000} = \frac{V_{out}}{1000}$$

$V_{offset} = \frac{V_{out}}{1000} = \frac{(\quad)}{1000} =$ _____

V_{offset} = mv

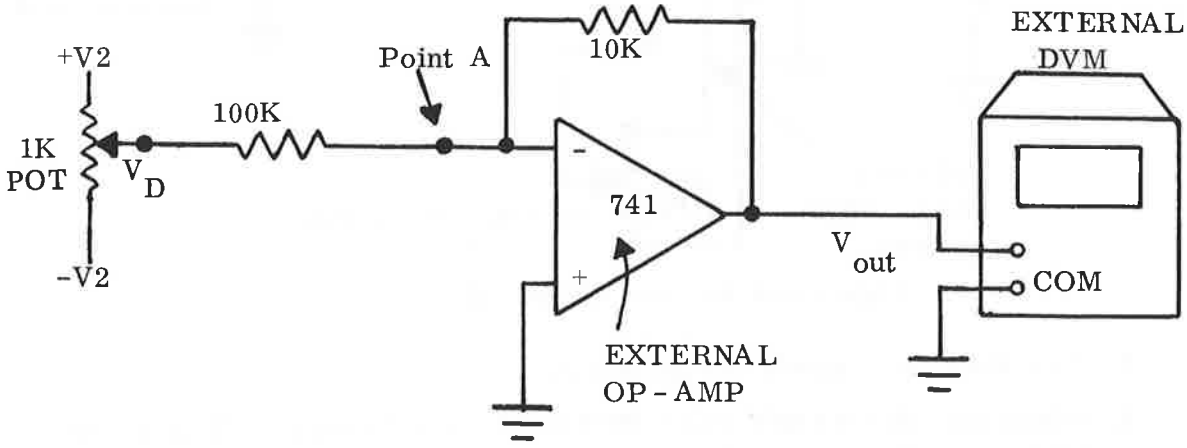


Figure 9-2 External OFFSET NULL

5. Wire the circuit shown in Figure 9-2.
6. The 1K pot provides an OFFSET NULL Voltage to the OP-AMP Inverting Input.
   Adjust the 1K pot for Zero volts Output
7. Connect the DVM to V_D. Record the Voltage needed to null the Offset in this circuit..

V_D = volts

Point A may now be used as the Input to the OP-AMP with no effects of OFFSET VOLTAGE.

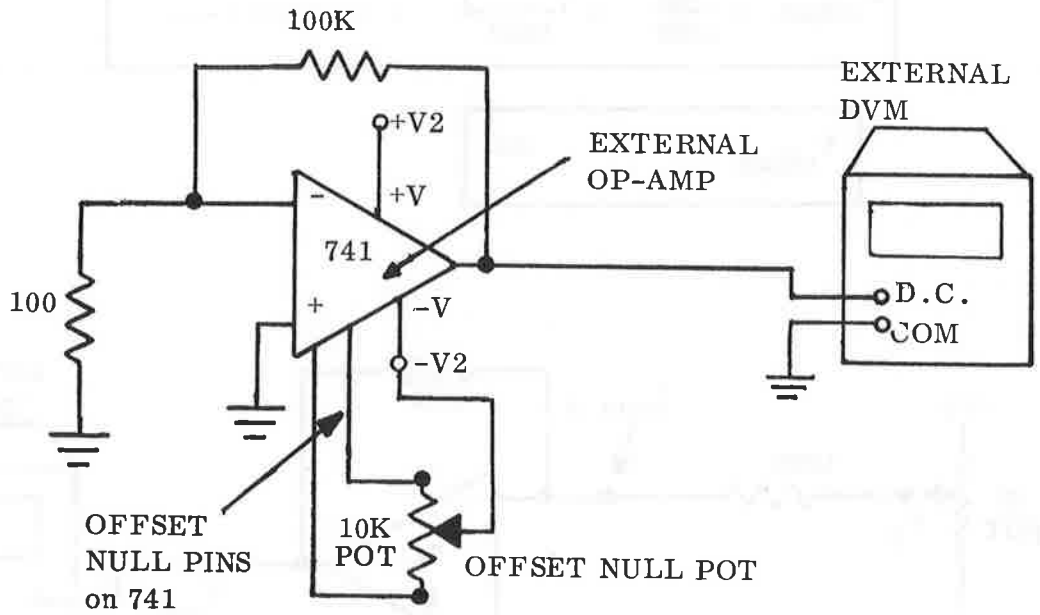


Figure 9-3 Internal Offset Null

8. Wire the circuit shown in Figure 9-3.
9. Adjust the 10K OFFSET NULL POT for Zero volts output. This is the point where the offset Voltage is Nulled.

Record the Output Voltage

V_{out} = volts

QUESTIONS:

1. What is a typical value for the Offset Voltage in a Modern OP-AMP?
2. Under what conditions of Gain does the Offset Voltage cause a problem?
3. What problem is caused by the Offset Voltage?

Ed-Lab	SUBTRACTOR (DIFFERENTIAL INPUT)	EXP. NO. 10 Page No. 1

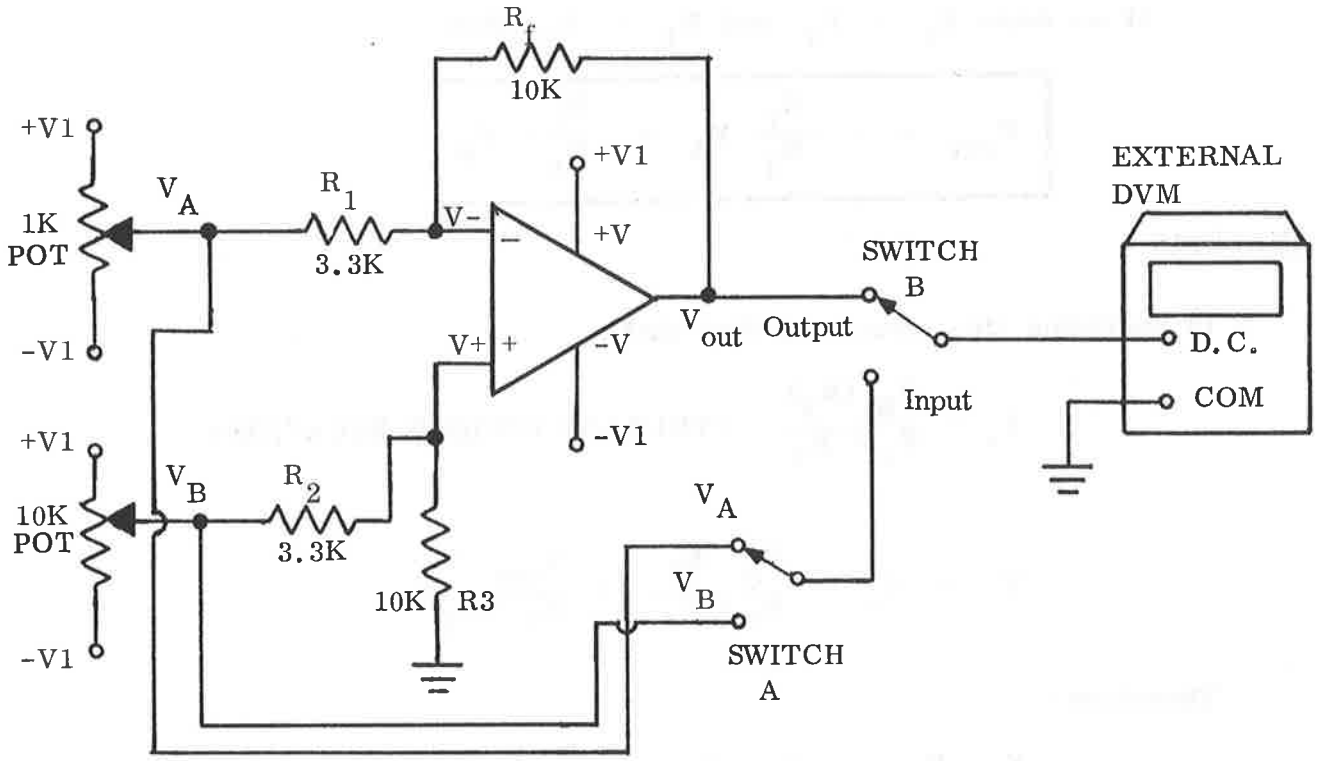


Figure 10-1 Differential Amplifier

OBJECTIVE:

To build and test a differential Amplifier using an OP-AMP.

DESCRIPTION:

The circuit shown in figure 10-1 is a differential amplifier. The purpose of this circuit is to produce an output voltage proportional to the difference between the two input voltages V_A and V_B.

The positive input voltage is applied to the Non-Inverting input. The voltage to be subtracted is applied to the Inverting Input circuit. The circuit resistors cause each input to be "weighted" by a factor which depends upon the values of the circuit resistors. The formula for the Output Voltage is given by:

$$V_{out} = - \frac{R_f + R_1}{R_1} \times \frac{R_f \ V_A}{R_f + R_1} + \frac{(R_f + R_1) \ R_3 \ V_B}{R_1 \ (R_3 + R_2)}$$

If we make $R_3 = R_f$ and $R_1 = R_2$ then:

$$V_{out} = -\frac{R_f}{R_1} V_A + \frac{R_f}{R_1} V_B$$

ANALYSIS:

In analyzing this circuit we find that:

$$V_+ \doteq \frac{V_B (R_3)}{R_3 + R_2} \quad \text{(VOLTAGE DIVIDER EQUATION)}$$

$$V_- = V_+ = \frac{V_A R_f}{R_f + R_1} + \frac{V_{out} R_1}{R_f + R_1}$$

Therefore:

$$\frac{V_A R_f}{R_f + R_1} + \frac{V_{out} R_1}{R_f + R_1} = \frac{V_B R_3}{R_3 + R_2}$$

$$\frac{V_A R_f}{R_f + R_1} - \frac{V_B R_3}{R_3 + R_2} = -\frac{V_{out} R_1}{R_f + R_1}$$

$$V_{out} = -\frac{R_f + R_1}{R_1} \left[\frac{V_A R_f}{R_f + R_1} - \frac{V_B R_3}{R_3 + R_2} \right]$$

By properly selecting R_1, R_2, R_3 and R_f we can obtain any desired difference gain.

Note that the gain of each input can be individually adjusted.

$$V_{out} = -\frac{(R_f + R_1)}{R_1}\frac{R_f V_A}{(R_f + R_1)} + \frac{(R_f + R_1) R_3}{R_1 (R_3 + R_2)} V_B$$

the gain for the two inputs are

$$\text{GAIN } (V_A) = -\frac{R_f}{R_1}$$

$$\text{GAIN } (V_B) = \frac{(R_f + R_1)}{R_1} \times \frac{R_3}{(R_3 + R_2)}$$

Note that the gain for input V_A is negative and the gain for input V_B is positive. This results in a differential output.

In the SUMMER Experiment (Experiment No. 8) we were also able to obtain the difference between two voltages by making one of them a negative value. Using the SUMMER circuit the gain was the same for both inputs and was adjustable by varying the feedback resistor.

If $R_3 = R_f$ and $R_1 = R_2$

Then $$V_{out} = -\frac{R_f}{R_1} V_A + \frac{R_f}{R_1} V_B = \frac{R_f}{R_1} (V_B - V_A)$$

$$V_{out} = \frac{R_f}{R_1} (V_B - V_A) \quad \text{for } R_3 = R_f, \; R_1 = R_2$$

PROCEDURE:

1. Wire the circuit shown in Figure 10-1.
2. With Switch B DOWN adjust the Input V_A and V_B to the Values indicated in the table below
3. With SWITCH B UP Record the Output Voltage

V_A SWITCH B DOWN SWITCH A UP	V_B SWITCH B DOWN SWITCH A DOWN	V_{out} SWITCH B UP	V_{out} CALCULATED $3 (V_B - V_A)$
0	0		
1.0	0		
0	1.0		

4. Calculate the Theoretical Value for each set of inputs in the Table of step 3.

$$V_{out} = \frac{10K}{3.3K} (V_B - V_A) = 3 (V_B - V_A)$$

Enter the Results in the column of the table.

5. How do the Calculated and Measured Output Voltages compare?
6. Explain any differences between Measured and Calculated V_{output} voltages.
7. Change R_3 from 10K to 1K

The gain for V_B will now be

$$\text{GAIN } (V_B) = \frac{R_f + R_1}{R_1} \times \frac{R_3}{(R_3 + R_2)} = \frac{10K + 3.3K}{3.3K} \times \frac{1K}{(1K + 3.3K)}$$

$$= \frac{13.3K}{3.3K} \left(\frac{1}{4.3}\right) = 0.94$$

Therefore:

$$V_{out} = 0.94V_B - 3V_A$$

8. Adjust V_A and V_B to the values indicated in the table below. Record the Measured Output Voltage.

V_A SWITCH B DOWN SWITCH A UP	V_B SWITCH B DOWN SWITCH A DOWN	V_{Out} SWITCH B UP	V_{out} CALCULATED $0.94\ V_B - 3V_A$
0	0		
1.0	1.0		
-1.0	-2.0		

9. Calculate the Theoretical Values for the V_A and V_B input voltage indicated in the table of step 8.
Use the formula:

$$V_{out} = 0.94\ (V_B) - 3\ (V_A)$$

Record the results in the table.

QUESTIONS:

1. What values of R_1, R_2, R_3 and R_f could you choose to obtain $V_{out} = V_B - V_A$?
2. Will this circuit work for A.C. input signals?
3. The differential input circuit is used when the signal lines to the OP-AMP are subject to external noise. Since the circuit is a differential amplifier, will the equal noise in both input lines cancel?

Ed-Lab	INTEGRATOR	EXP. NO. 11 Page No. 1

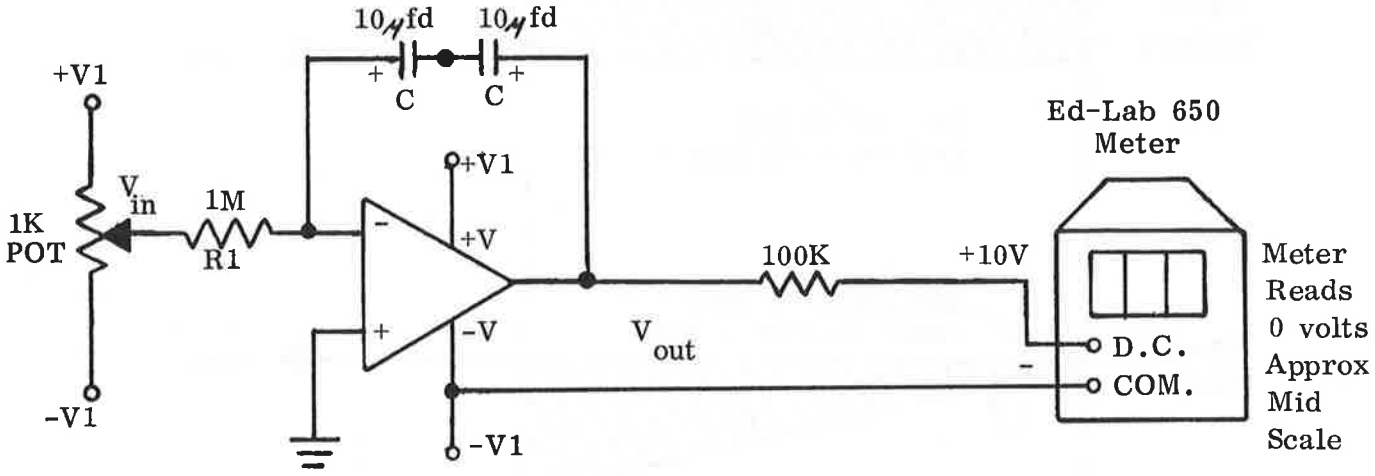


Figure 11-1 Low Speed Integrator

OBJECTIVE:

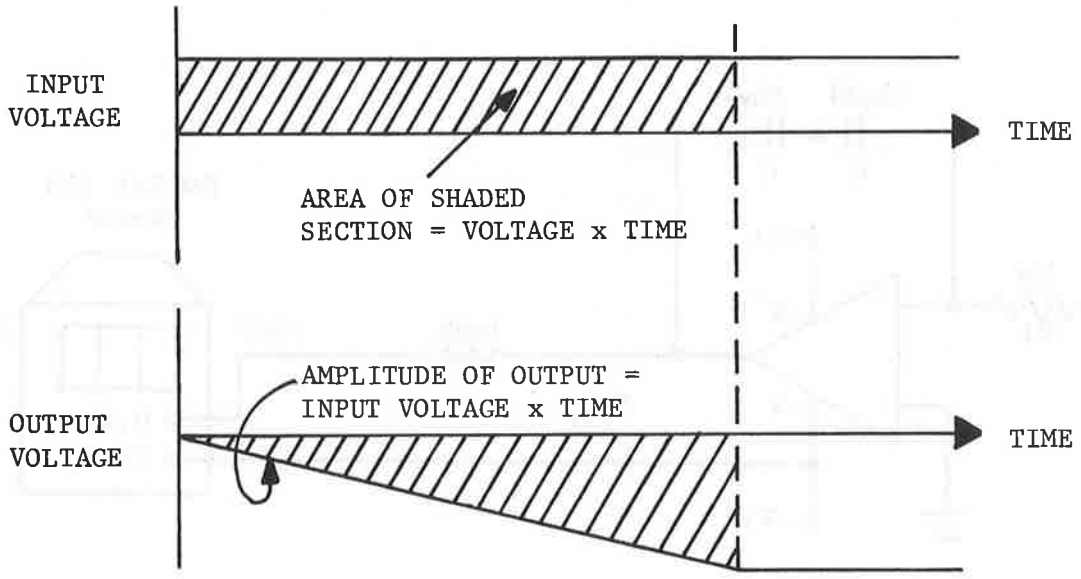
To build and test an INTEGRATOR circuit and observe the operation.

DESCRIPTION:

Figure 11-1 is an INTEGRATOR circuit. Note that it has the same form as the Inverting Amplifier, but the feedback resistor has been replaced by an Integrator Capacitor C.

The use of the capacitor as the feedback element turns the inverting amplifier circuit into an Integrator. As the capacitor charges during the circuit operation, the output voltage generated is proportional to the Amplitude of the Input Voltage multiplied by the length of time the Input Signal is applied.

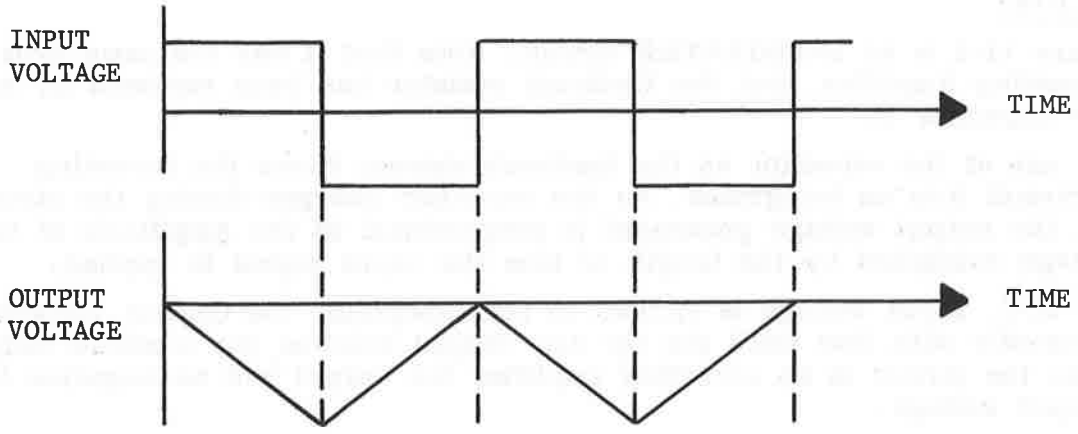
If a D.C. Input voltage is applied to the Integrator the Output Voltage will increase steadily with time until the Op-Amp output reaches the maximum output level. Since the circuit is an inverting amplifier the output will be negative for a positive input voltage.



INTEGRATOR INPUT/OUTPUT VOLTAGE

The Amplitude of the Output Voltage increases with time for the length of time that the Input Voltage is applied. Note that the Output voltage reaches a maximum and then levels off.

If a Square Wave is applied to the Input of an Integrator the Output Voltage will increase linearly in the opposite direction of the input voltage. The result is a Triangle Wave.



Integration is useful to detect small error voltages in feedback systems and to generate special waveforms.

ANALYSIS:

The current in R1 is

$$I_{R1} = \frac{V_{in}}{R1}$$

The current in the capacitor must be equal to this current, since the current into the Inverting Input is zero.

$$I_c = I_{R1} = - C \frac{dv}{dt}$$

The value of the voltage across the capacitor will be

$$V_c = \frac{-1}{C} \int_o^t idt = \int_o^t \frac{V_{in}}{R1} \times dt = V_{output}$$

$$V_{output} = \frac{-1}{CR1} \int_o^t V_{in} \, dt$$

Therefore the Output Voltage is the Integral of the input voltage with time.

PROCEDURE:

1. Wire the circuit shown in Figure 11-1.
2. Center the 1K pot. Adjust the pot so the output voltage is changing. In Order to do this you must adjust the 1K pot to generate an input voltage and then wait for the circuit to Integrate this voltage and change the Output Voltage. Reverse the direction a few times.
3. Does the Output Voltage change Linearly with time?
4. Try to adjust the 1K pot so the Output Meter reads 6 volts on the 10 volt scale.
   Note: To stop the output voltage change you must set the 1K pot for Zero volts, exactly.

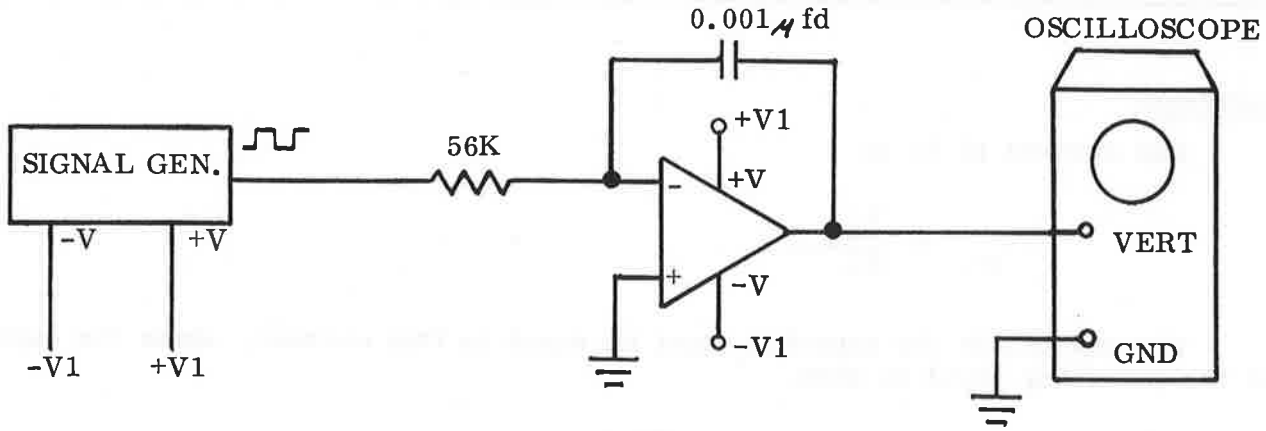
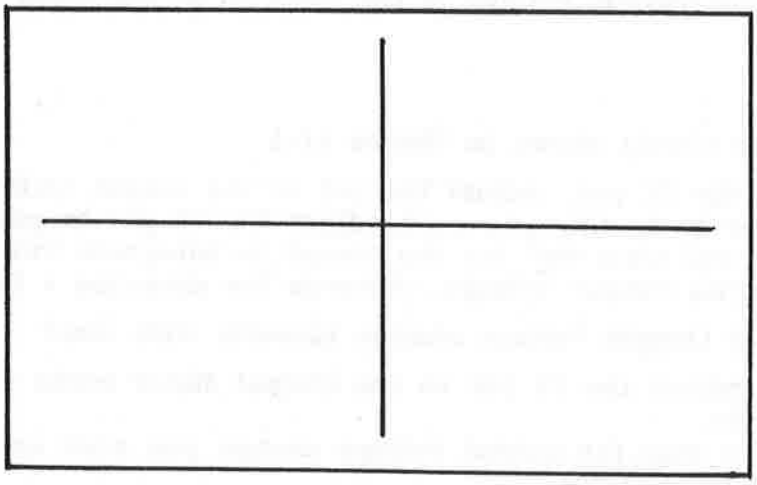


Figure 11-2 High Speed Integration

5. Wire the circuit shown in Figure 11-2. This is a high speed integrator driven with the Square wave output of the Signal Generator. When the Square wave is Positive the Integrator output will descend linearly to the negative limit of the OP-AMP or until the square wave voltage reverses.
When the Square wave is Negative the Integrator output will increase linearly to the Positive limit of the OP-AMP or until the Square Wave Reverses.

6. Sketch the Output Waveform measured on Figure 11-2.

OUTPUT WAVEFORM



QUESTIONS:

1. Can the Integrator be used to generate linear voltage Ramps?
2. What is the function of the Input Resistor on the Integrator?
3. What is the Input Impedance of the Integrator?
4. Which circuit components effect the speed of integration?

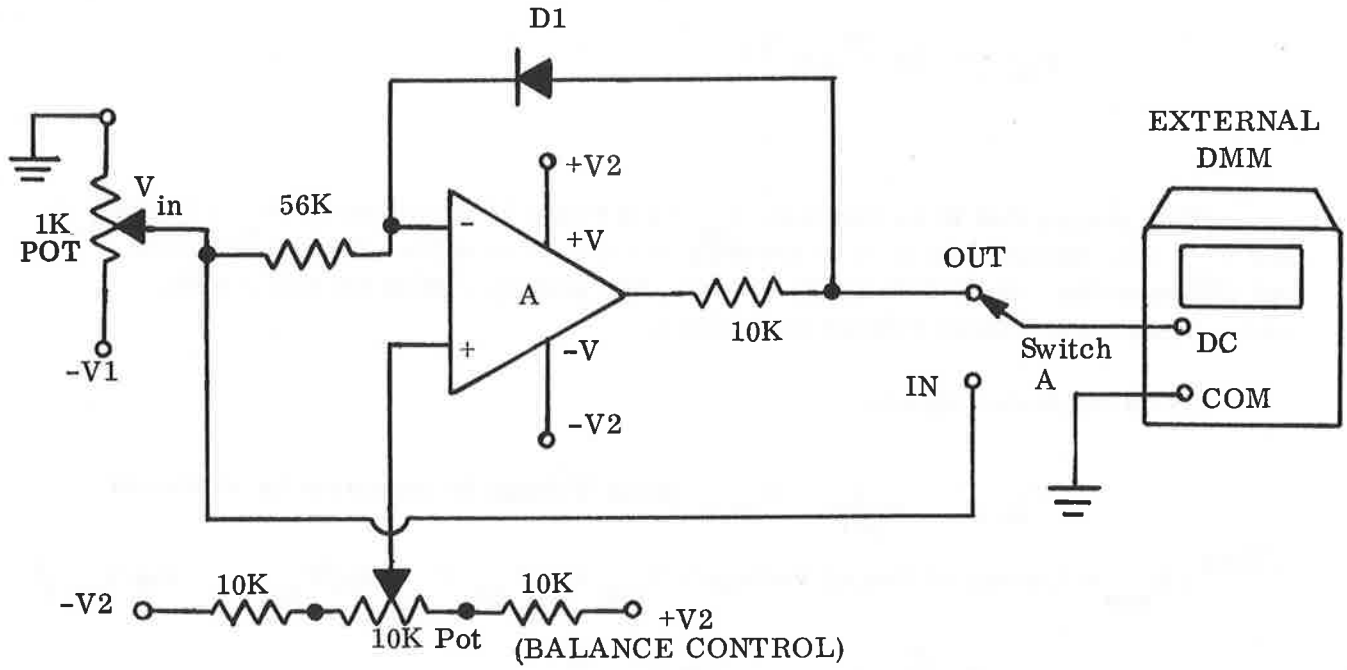


Figure 12-1 Log Amplifier

OBJECTIVE:

To build and test an OP-AMP LOG Amplifier. The student will plot the input versus output voltage curve and prove that the amplifier exhibits a LOG amplification characteristic.

DESCRIPTION:

A LOG Amplifier has the characteristic that the Output Voltage is proportional to the LOG of the Input Voltage.

A logarithmic amplifier is used in a situation which requires the amplifier gain to be proportional to the Amplitude of the input signal.

For example, an amplifier used in a radio communications receiver must be able to accept and amplify very small, weak signals and also large very strong signals. If the amplifier gain is very high to properly amplify the weaker signals then a strong signal would cause the amplifier to "saturate". On the other hand, if the amplifier gain is low to prevent saturation caused by strong signals the gain will not be high enough to amplify the weaker signals. The solution is to construct an amplifier circuit which has high gain for small input voltages and low gain for large input voltages.

The Log Amplifier gain is inversely proportional to the input voltage.

$$\boxed{V_{out} = K \log V_{in}} \quad \text{where K = Constant}$$

$$\frac{V_{out}}{K} = \log V_{in}$$

$$V_{in} = 10^{(V_{out}/K)}$$

This means that if we increase V_{in} by a factor of 10 (Increase V_{in} 10 times) the V_{out} will increase by K (the constant scale factor) volts. In fact each time we increase the Input Voltage by 10 times the previous value we will see the same increase in Output Voltage of K volts.

As an example suppose

$$V_{in\ 1} = \frac{1}{10} V_{in\ 2}$$ (Input Voltage is Increased by 10 times)

Then ΔV_{out} = Change of Output Voltage = $V_{out\ 2} - V_{out\ 1} = K \log(V_{in\ 2} - \log V_{in\ 1})$

$$\Delta V_{out} = K \left[\log V_{in\ 2} - \log V_{in\ 1}\right]$$

$$\Delta V_{out} = K \log \left(\frac{V_{in\ 2}}{V_{in\ 1}}\right) = K \log 10 = K$$

$$\boxed{\Delta V_{out} = K}$$

Therefore if the Input Voltage changes from 0.01 volts to 0.1 volts (total change of 0.09 volts) the Output Voltage will increase by K volts.

If the Input Voltage increases again from 0.1 volts to 1.0 volts (total change of 0.9 volts) the Output Voltage will again increase by K volts.

Any time the input voltage is increased by a constant multiple the output voltage will increase by a constant amount.

Figure 12-1 shows a Log Amplifier. The feedback element is a Diode. The basic configuration is that of an Inverting Amplifier with R_f replaced by D1. This diode feedback element is the device that controls the Amplifier Gain and produces the Log output.

A forward biased diode has a logarithmic Voltage/Current curve shown in Figure 12-2.

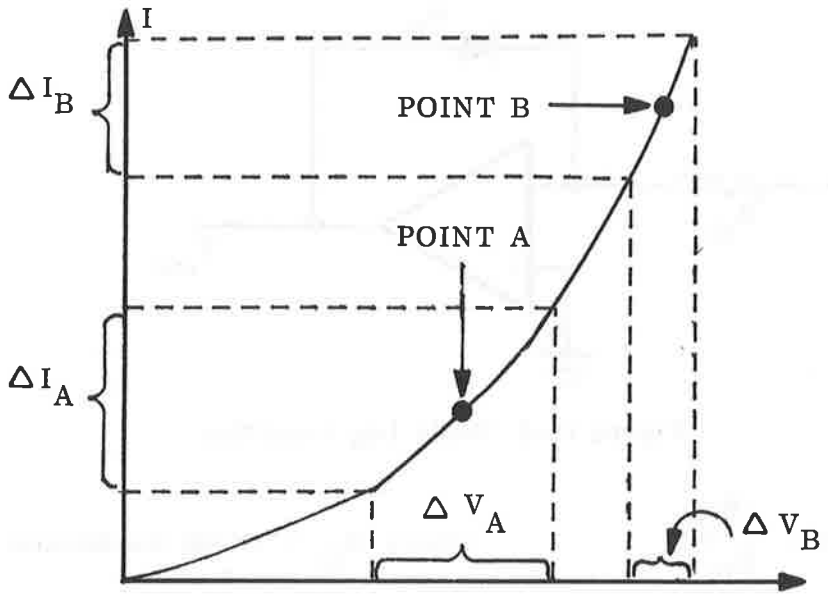


Figure 12-2 V-I curve for a Diode

The diode resistance is a function of the diode voltage. The slope of the curve at any particular diode voltage determines the diode resistance.

At POINT A in Figure 12-2 the diode resistance is:

$$R_A = \frac{\Delta V_A}{\Delta I_A}$$

At POINT B in Figure 12-2 the diode resistance is:

$$R_B = \frac{\Delta V_B}{\Delta I_B}$$

Inspection of the Figure 12-2 shows that

R_B will be much smaller than R_A.

As the Voltage across the diode Increases the diode resistance Decreases. The Diode Resistance Decreases Logarithmically with the Diode Voltage.

When the Diode is used as a feedback element in an inverting amplifier as shown in Figure 12-3, The result is a LOG AMPLIFIER

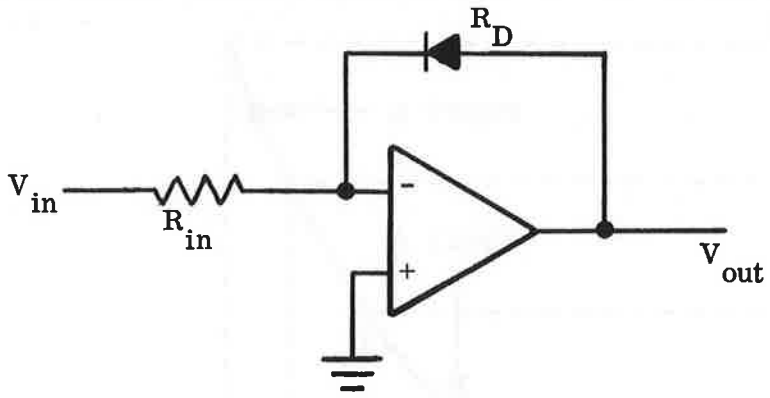


Figure 12-3 Basic Log Amplifier

$$\text{GAIN} = \frac{-R_D}{R_{in}} \qquad \text{where } R_D = \text{Diode Resistance}$$

In order for this circuit to function as a LOG Amplifier the Diode must be Forward Biased. This means that the circuit will work only for V_{in} negative. V_{out} will always be positive.
Note in Figure 12-1 that the V_{in} can only be negative.

Figure 12-1 also indicates a 10K resistor in the OP-AMP output to Limit the current through the Diode. There is also a Balance POT (10K) to zero the Output Voltage . This additional Balance is needed because the Gain is very high for Low Output Voltages.

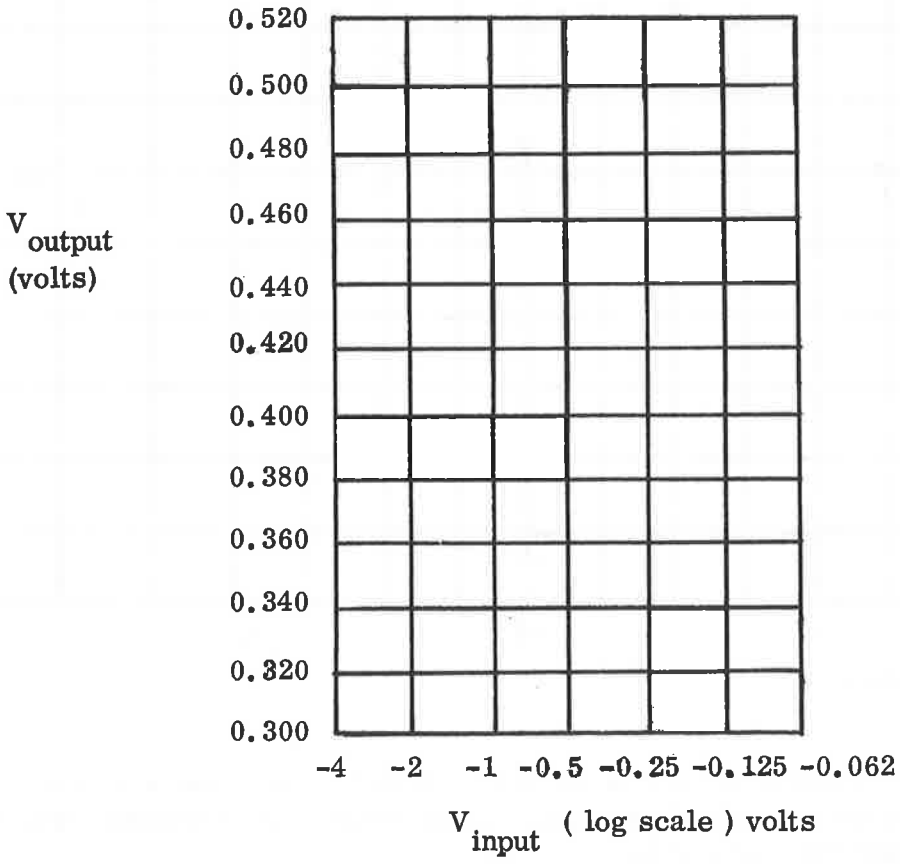
PROCEDURE:

1. Wire the Circuit shown in Figure 12-1.
2. Adjust the V_{input} (SWITCH A DOWN) for -4.00 volts.
3. Place SWITCH A UP to Monitor the Output Voltage
4. Adjust the 10K Balance Pot for an output voltage of 0.500 volts.
5. Set the V_{input} (1K Pot SWITCH A DOWN) at the levels indicated in the Table below and Record the Output Voltage (SWITCH A UP.)

V_{in} SWITCH A DOWN	V_{out} SWITCH A UP
-4	0.50
-2	
-1	
-0.5	
-0.25	
-0.125	
-0.062	

Note: To easily achieve the lower input voltages simply reduce the -V1 Power Supply Pot setting to reduce the maximum input voltage available on the 1K input pot.

6. Plot the Results in the Graph below



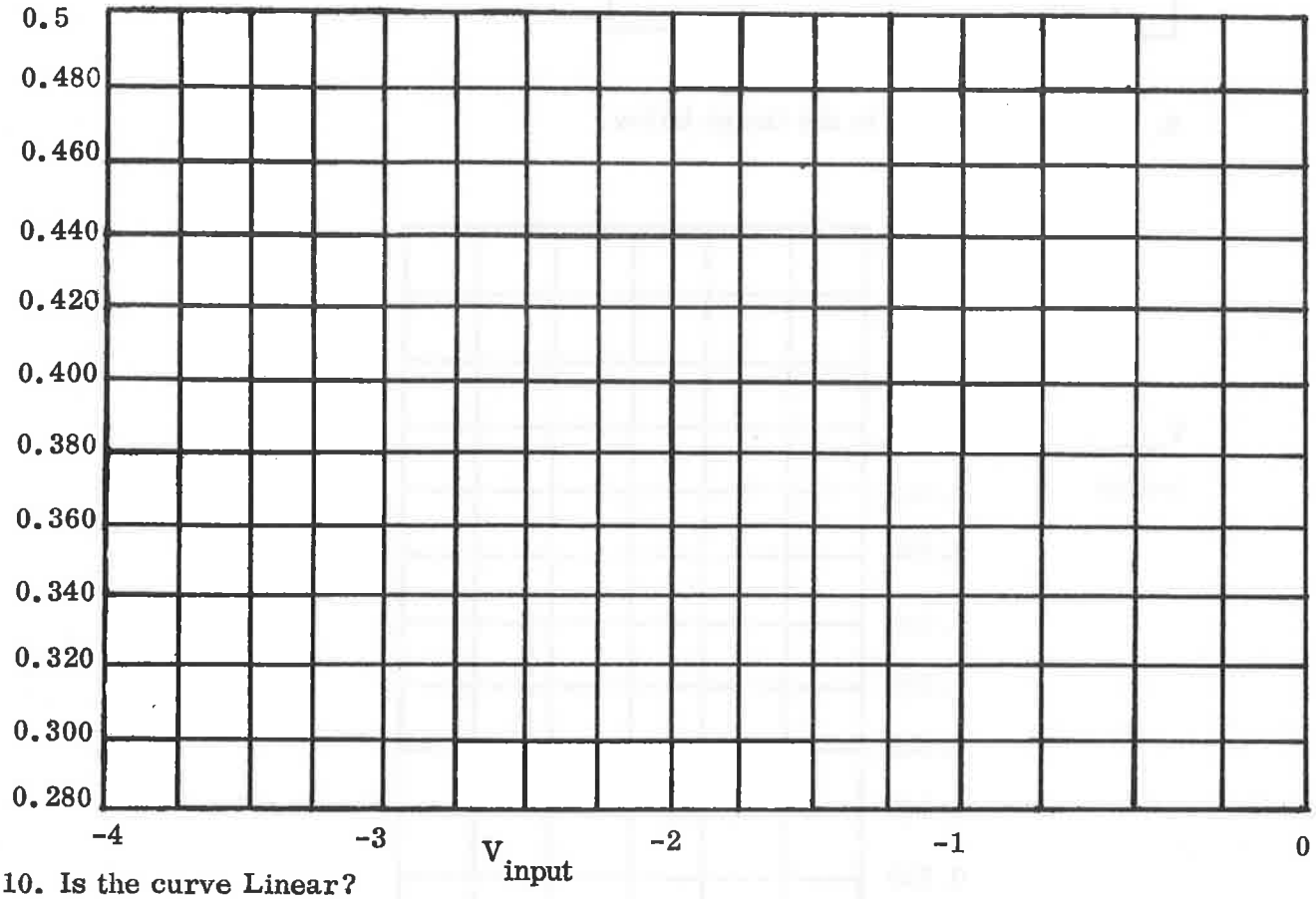
7. Is the curve Linear?

8. When the Input Voltage Doubles, what is the Change in Output Voltage?

V_{change} =

9. The curve of step 6 is linear because the V_{input} is designed to have equal spacing each time the input voltage doubles.

Plot the Data from step 5 on the LINEAR graph below



10. Is the curve Linear?

QUESTIONS:

1. What would be the effect on the operation of the circuit if the Diode were reversed.
2. Since the gain decreases with when input signal amplitude increases, will this help prevent amplifier saturation?
3. Is this amplifier sensitive to Changes in small input signals as well as large input signals?

Ed-Lab	LOG AMP WITH GAIN	EXP. NO. 13 Page No. 1

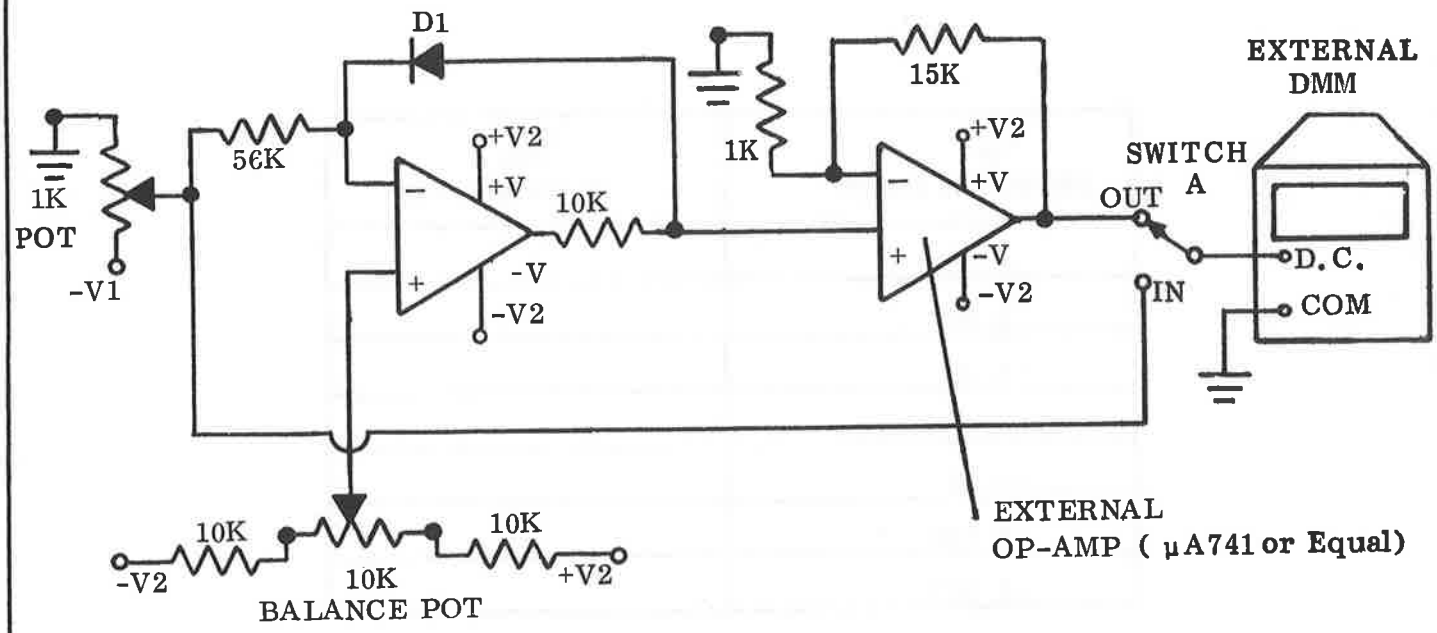


Figure 13-1 Log Amplifier with Gain

OBJECTIVE:

You will add a linear amplifier to the LOG AMPLIFIER tested in Experiment No. 12 so the Output Voltage swing will be much larger and easier to read.

DESCRIPTION:

The circuit shown in Figure 13-1 is the LOG AMPLIFIER of Experiment No. 12 followed by a NON-INVERTING LINEAR AMPLIFIER. The Linear Amplifier has a Gain of 16.

An external OP-AMP must be used to build the Linear Amplifier. Plug the External OP-AMP into the I.C. socket and wire per figure 13-1. The 741 op-amp can be used for this circuit.

PROCEDURE:

1. Wire the circuit shown in Figure 13-1. Note that an External OP-AMP chip must be used to build the Non-Inverting Amplifier.

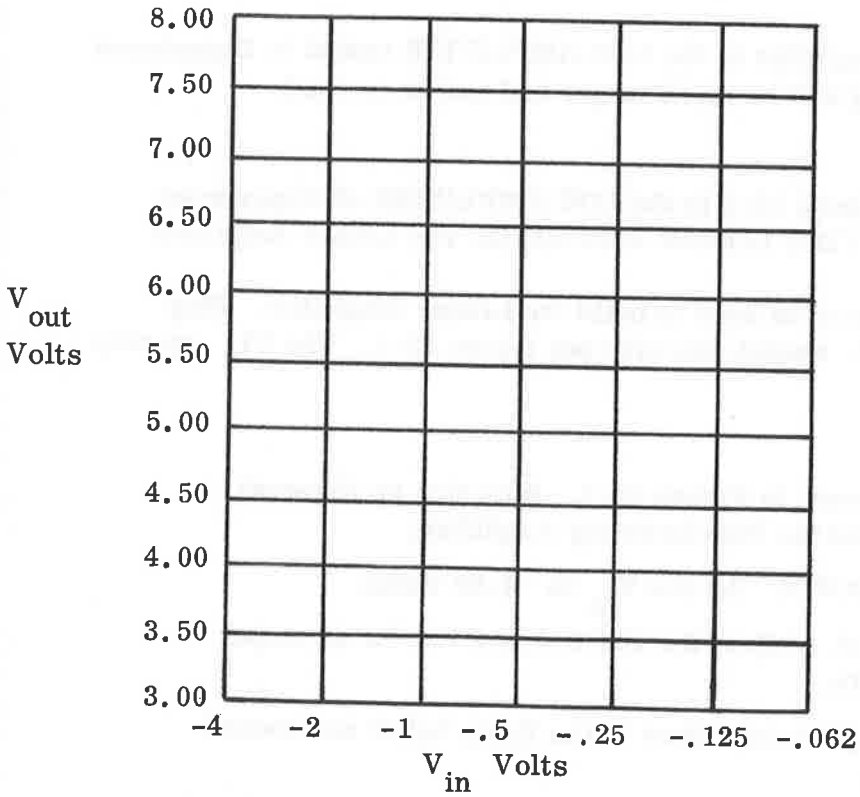
2. Place SWITCH A DOWN. Set the V_{in} to -4.00 volts.

3. Place SWITCH A UP. Adjust the 10K Balance Pot for an output voltage of approximately 7.00 volts.

4. Set the Input Voltage to the values in the Table below and record the Output Voltage.

V_{in} SWITCH A DOWN	V_{out} SWITCH A UP
-4.00	
-2.00	
-1.00	
-0.50	
-0.25	
-0.125	
-0.062	

5. Plot the Data on the Graph Below



Note: Do not use any negative output voltages as they are not valid.

6. Is the Curve Linear?

7. What is the Change in Output Voltage when the Input Voltage is doubled?

V_{output} Change =

QUESTIONS:

1. What is the Output Impedance of this LOG AMP with Gain?

2. What are the advantages of using this circuit instead of the circuit tested in Experiment No. 12?

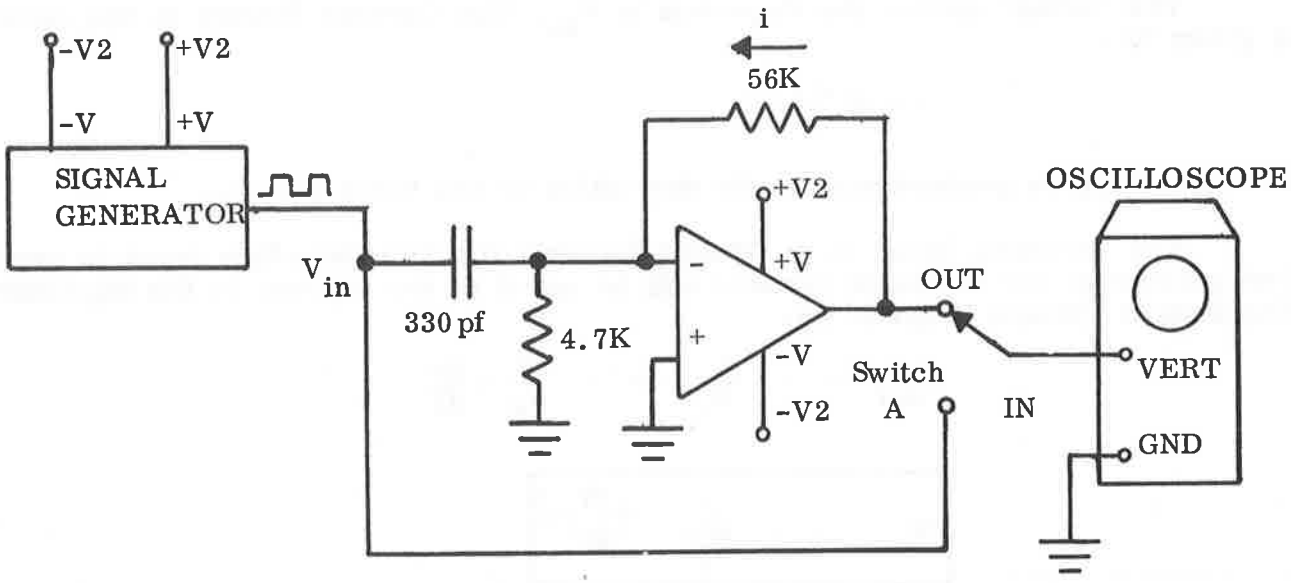


Figure 14-1 Differentiator

OBJECTIVE:

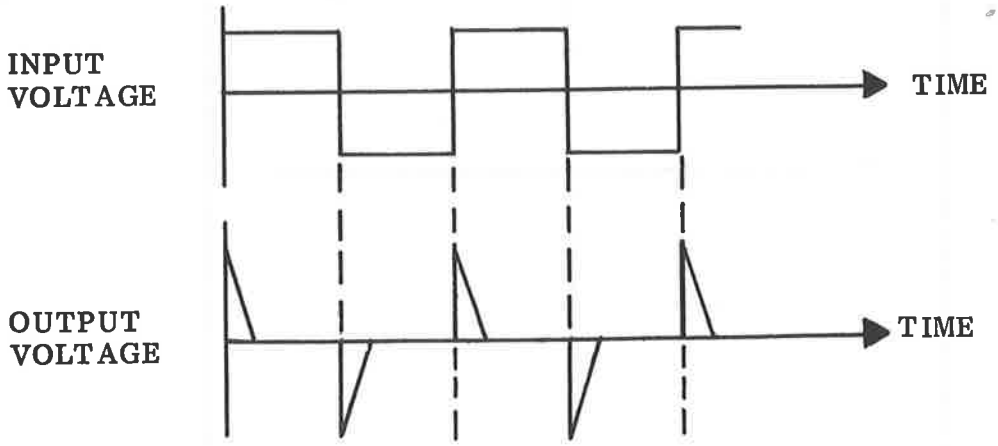
To build and test a Differentiator OP-AMP Circuit.

DESCRIPTION:

Figure 14-1 shows the circuit for a DIFFERENTIATOR. The circuit has the same configuration as the Inverting Amplifier with the exception that R_{in} is replaced with a Capacitor.

The Output of a Differentiator is proportional to the rate of change in the Input Voltage. This feature is useful when it is desirable to detect the change in an electronic signal.

If a Square Wave is applied to the input of a Differentiator the Differentiator output will be present only for the Edges of the Input Waveform.



DIFFERENTIATOR INPUT/OUTPUT WAVEFORMS

The Voltage across the Capacitor is V_{in}. The Current flowing in the capacitor is given by:

$$i = C \frac{dv}{dt}$$

so the current is proportional to the derivative of the input voltage.

The Inverting input is at Ground because the Non-Inverting Input is grounded. The current in the feedback resistor will be equal to the current in the capacitor. The Output Voltage is given by:

$$V_{out} = - \frac{i}{R_f} = - \frac{C}{R_f} x \frac{dv}{dt}$$

$$\boxed{V_{out} = - \frac{C}{R_f} \cdot \frac{d(V_{in})}{dt}}$$

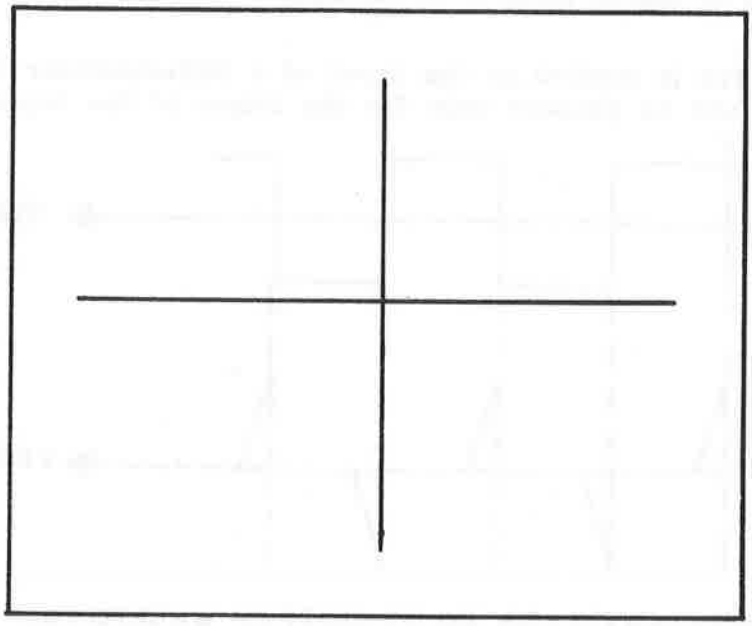
so the Output Voltage is proportional to the derivative of the Input Voltage.

The 4.7K resistor from the Inverting Input to ground prevents ringing or oscillation in the circuit.

PROCEDURE:

1. Wire the Circuit shown in Figure 14-1.
2. Place SWITCH A DOWN. Sketch the Input Voltage.

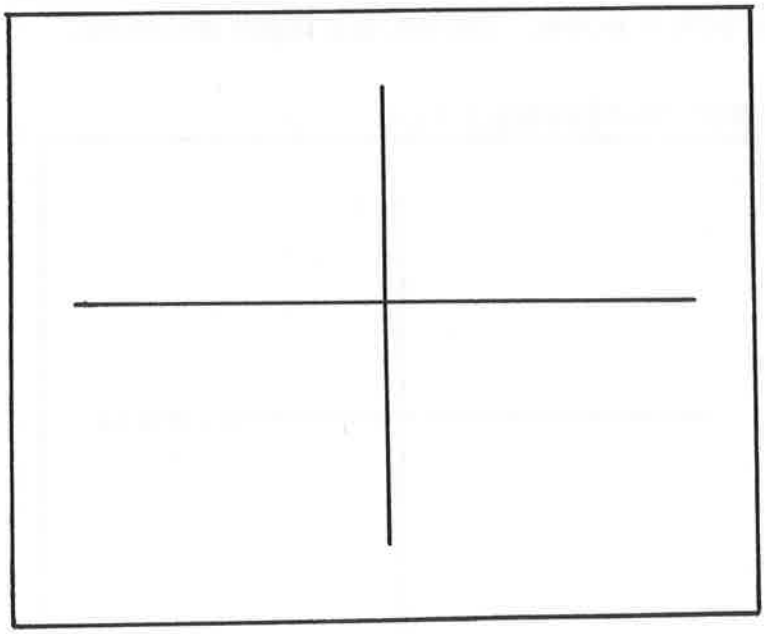
INPUT WAVEFORM (⎍⎍⎍)



3. Place SWITCH A UP. Sketch the Output Voltage.

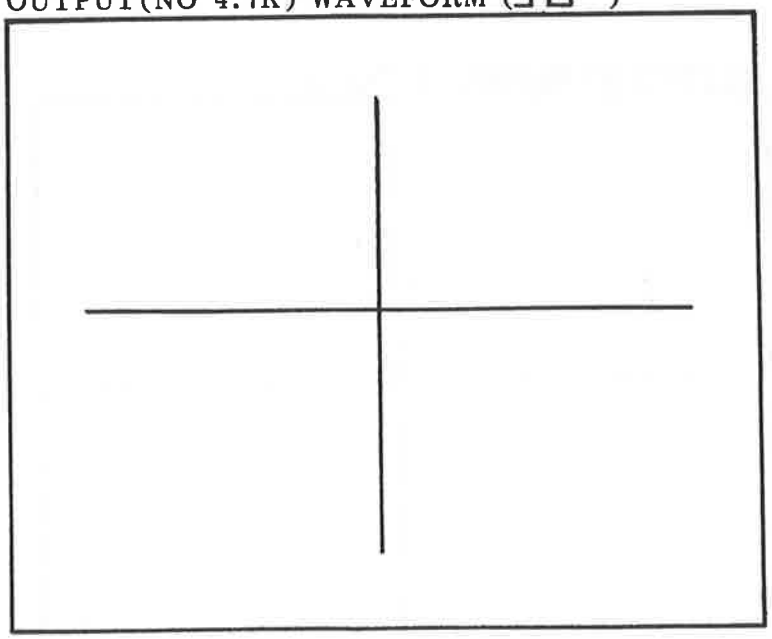
INPUT WAVEFORM

OUTPUT WAVEFORM (⎍⎍)



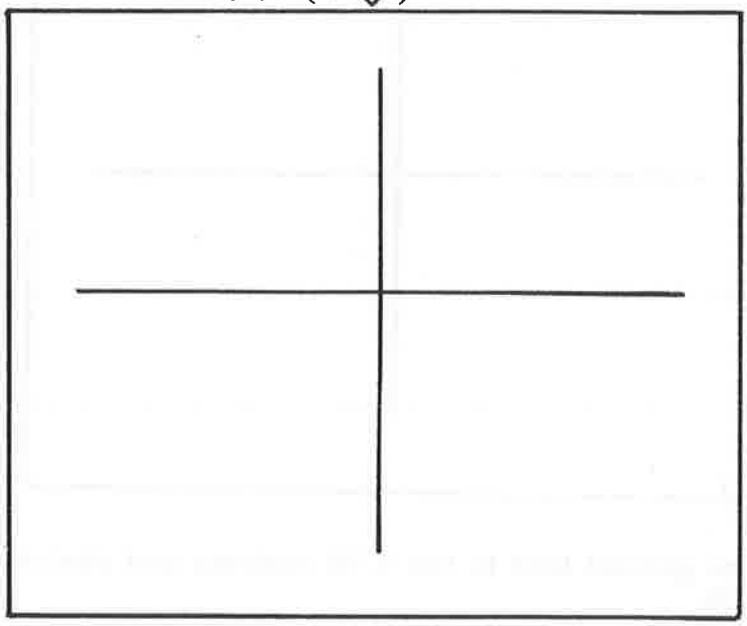
4. Remove the ground lead to the 4.7K resistor and sketch the OUTPUT WAVEFORM.

OUTPUT(NO 4.7K) WAVEFORM (⎍⎍)



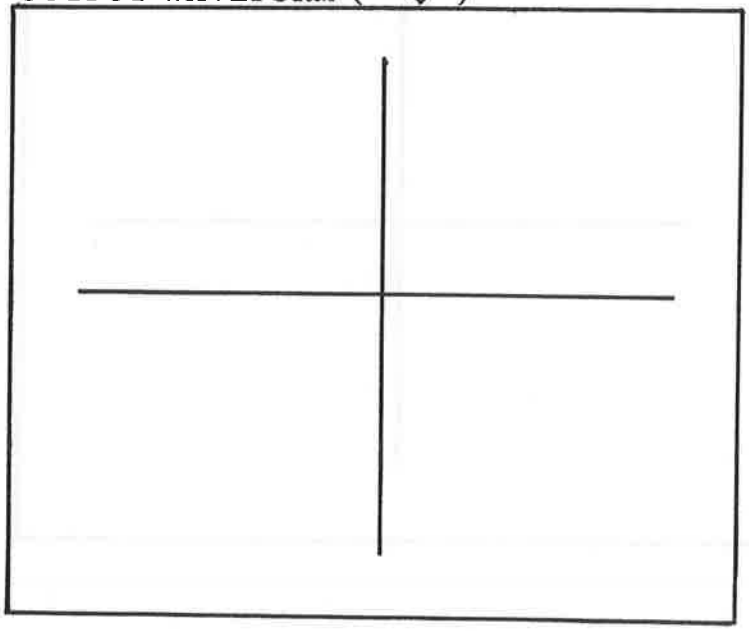
5. Reconnect the 4.7K resistor to ground.
6. Change the connection of the signal generator output from the Square Wave to the Triangle Wave Output.
7. Place SWITCH A DOWN. Sketch the Input Waveform.

INPUT WAVEFORM (∿)



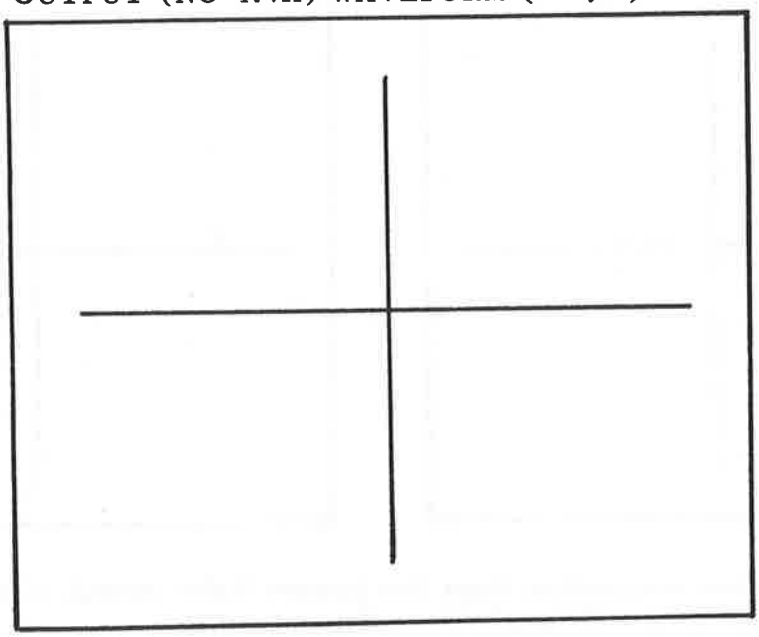
8. Place SWITCH A UP. Sketch the Output Waveform

OUTPUT WAVEFORM (∿)



9. Remove the ground connection from the 4.7K resistor.
10. Sketch the Output Waveform

OUTPUT (NO 4.7K) WAVEFORM (∿)



11. What is the effect of removing the 4.7K resistor?
12. Does the circuit act as a differentiator?
13. Another form of the Practical Differentiator is shown in Figure 14-2.

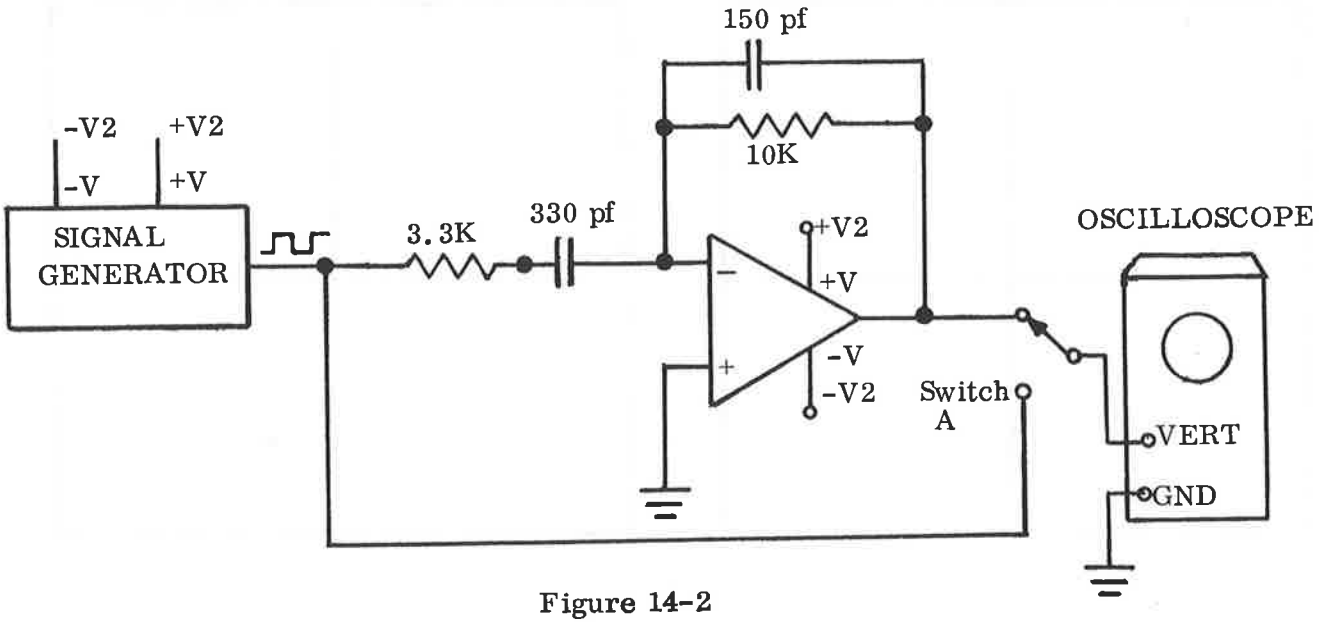
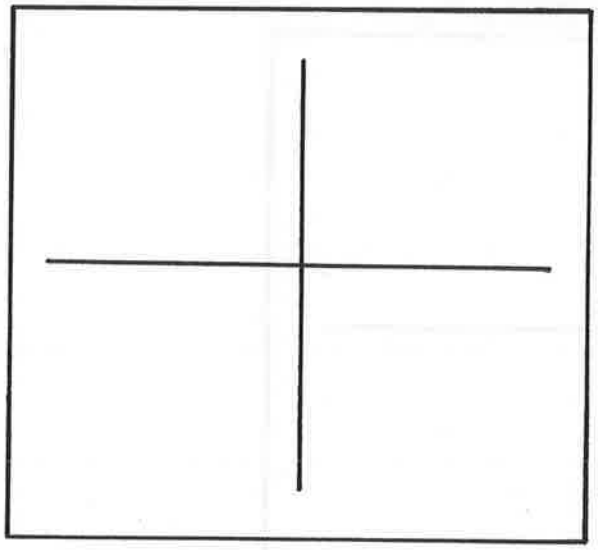


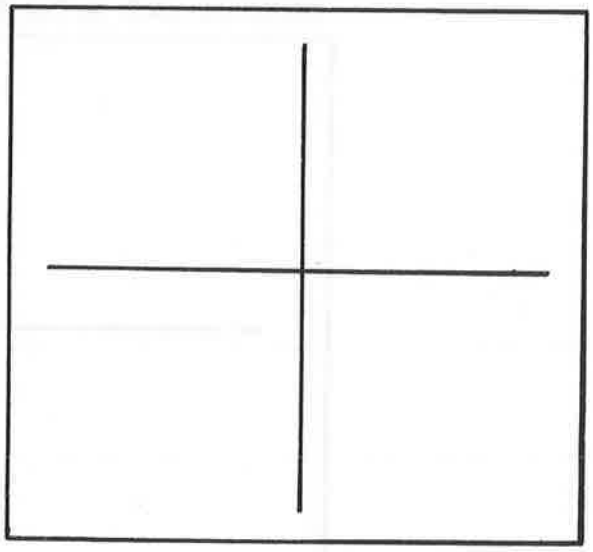
Figure 14-2

14. Wire the circuit shown in Figure 14-2.
15. Sketch the Input and Output Waveforms below:

INPUT WAVEFORM(⎍⎍)

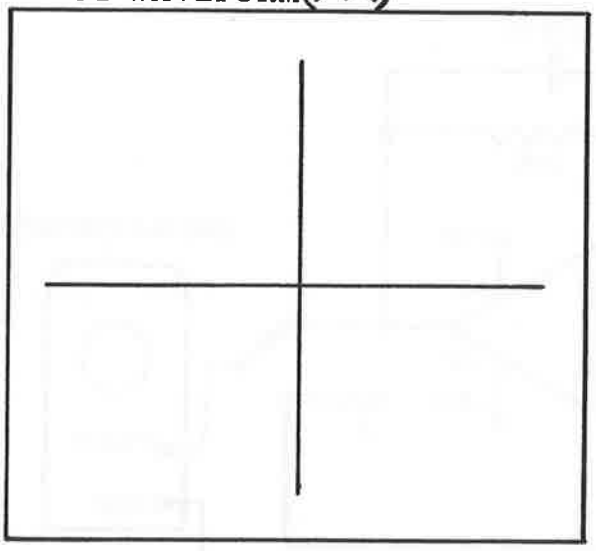


OUTPUT WAVEFORM(⎍⎍)

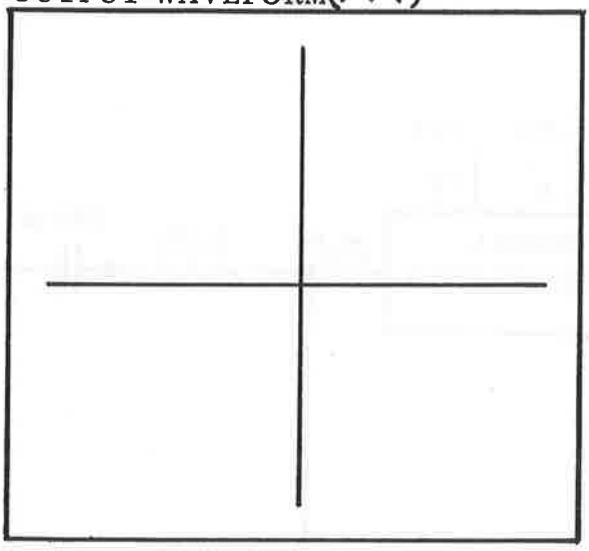


16. Change the connection from the Square Wave output of the Signal Generator to the Triangle Wave Output pin.
17. Sketch the Input Waveform and Output Waveform below:

INPUT WAVEFORM(∧∧)



OUTPUT WAVEFORM(∧∧)



Ed-Lab	ULTRA LINEAR RECTIFIER	EXP. NO. 15 Page No. 1

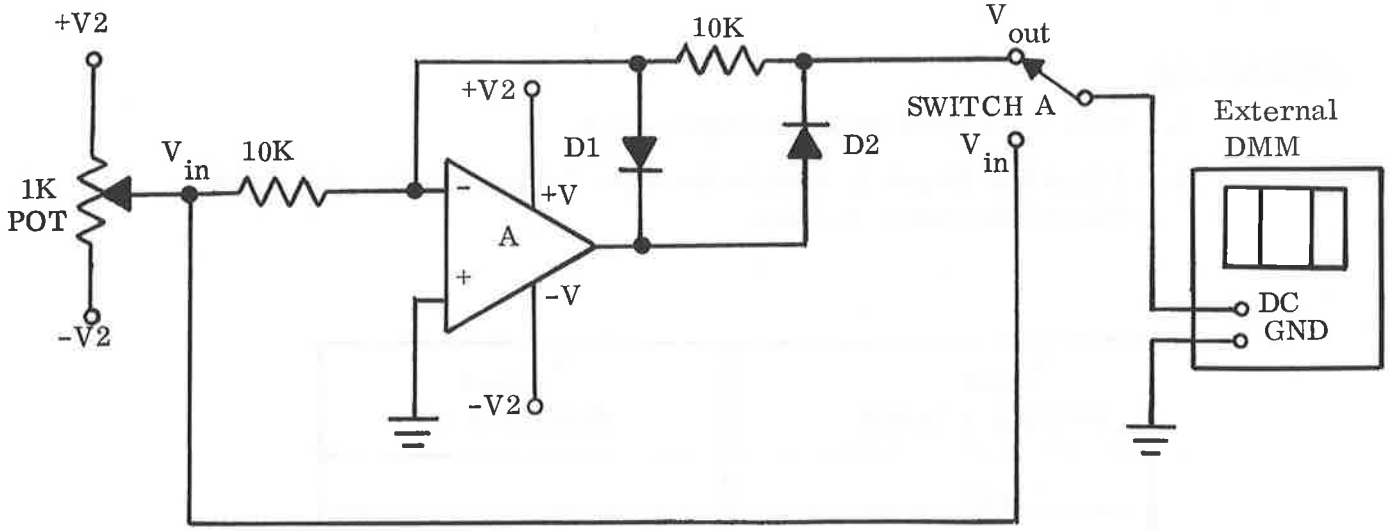


Figure 15-1 Ultra Linear Rectifier

OBJECTIVE:

To build and test a Linear Half Wave Rectifier. Input and Output Waveforms will be measured.

DESCRIPTION:

There are many applications of the Rectifier which require high linearity. A single diode rectifier always introduces a diode drop in voltage between the input and output. This makes the diode rectifier inaccurate for small input voltages. Also, since the Diode resistance changes with current, the diode rectifier output will be slightly non-linear throughout the input voltage range. When a linear rectifier is required the circuit shown in figure 15-1 is used. One application of a Linear Rectifier is to realize A.C. voltmeter functions. The A.C. input signal to be measured must be rectified and converted to a D.C. level, exactly proportioanal to the A.C. input signal. This D.C. voltage is then used to drive a meter movement which is calibrated in A.C. volts.

When a Positive input voltage is applied to the circuit in Figure 15-1 Diode D1 will be biased ON, shorting the OP-AMP output to the Inverting Input. This will cause the output to be Zero for any Positive Input Voltage.

When the Input Signal is Negative, diode D1 will be reverse biased (open circuit) and diode D2 will be forward biased (shorted). Feedback with D2 forward biased will be through the 10K feedback resistor. The amplifier will have a gain of 1 and the Output Voltage will be the exact inversion of the Input Voltage.

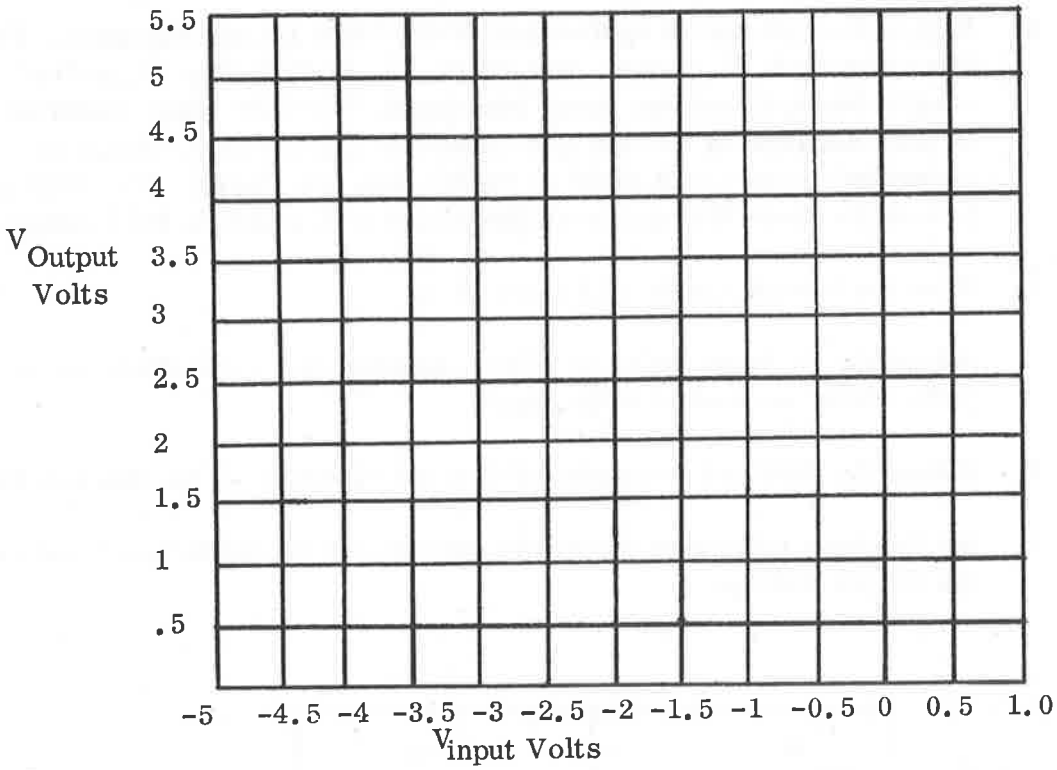
Note that the output is taken at the Cathode of D2, not at the OP-AMP output. This eliminates the error caused by the Diode Voltage Drop across D2.

PROCEDURE:

1. Wire the circuit shown in Figure 15-1.
2. Adjust the 1K pot to achieve the Input Voltages in the table below. Record the Output Voltage.

V_{input} SWITCH A DOWN	V_{output} SWITCH A UP
+1.00	
+0.10	
+0.00	
-0.10	
-0.50	
-1.00	
-2.00	
-3.00	
-4.00	
-5.00	

3. Plot the Data taken in step 2 on the Graph below:



4. Is the Output Linear for Negative Input Voltages?

5. Ultra Linear Rectifier Application

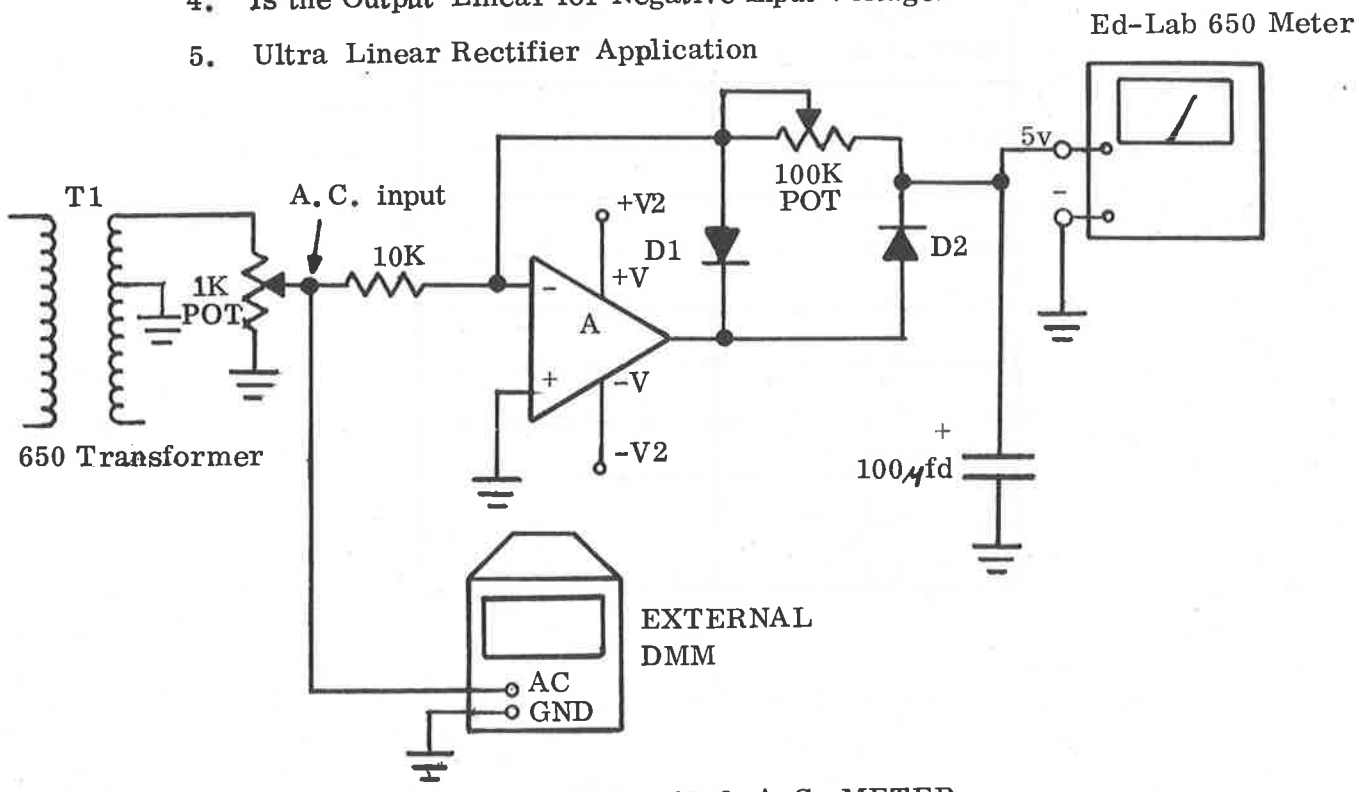


Figure 15-2 A.C. METER

6. Figure 15-2 shows an application of the Ultra Linear Rectifier. The circuit is an A.C. Meter. The Ultra-Linear Rectifier is used to rectify the A.C. voltage being measured. The half wave rectified output is peak detected by the 100 μfd capacitor and the D.C. output is connected to the 5 volt input on the Ed-Lab 650 Meter. The 100K pot is used to scale the meter so the meter will measure RMS voltage.

7. Wire the circuit shown in Figure 15-2.

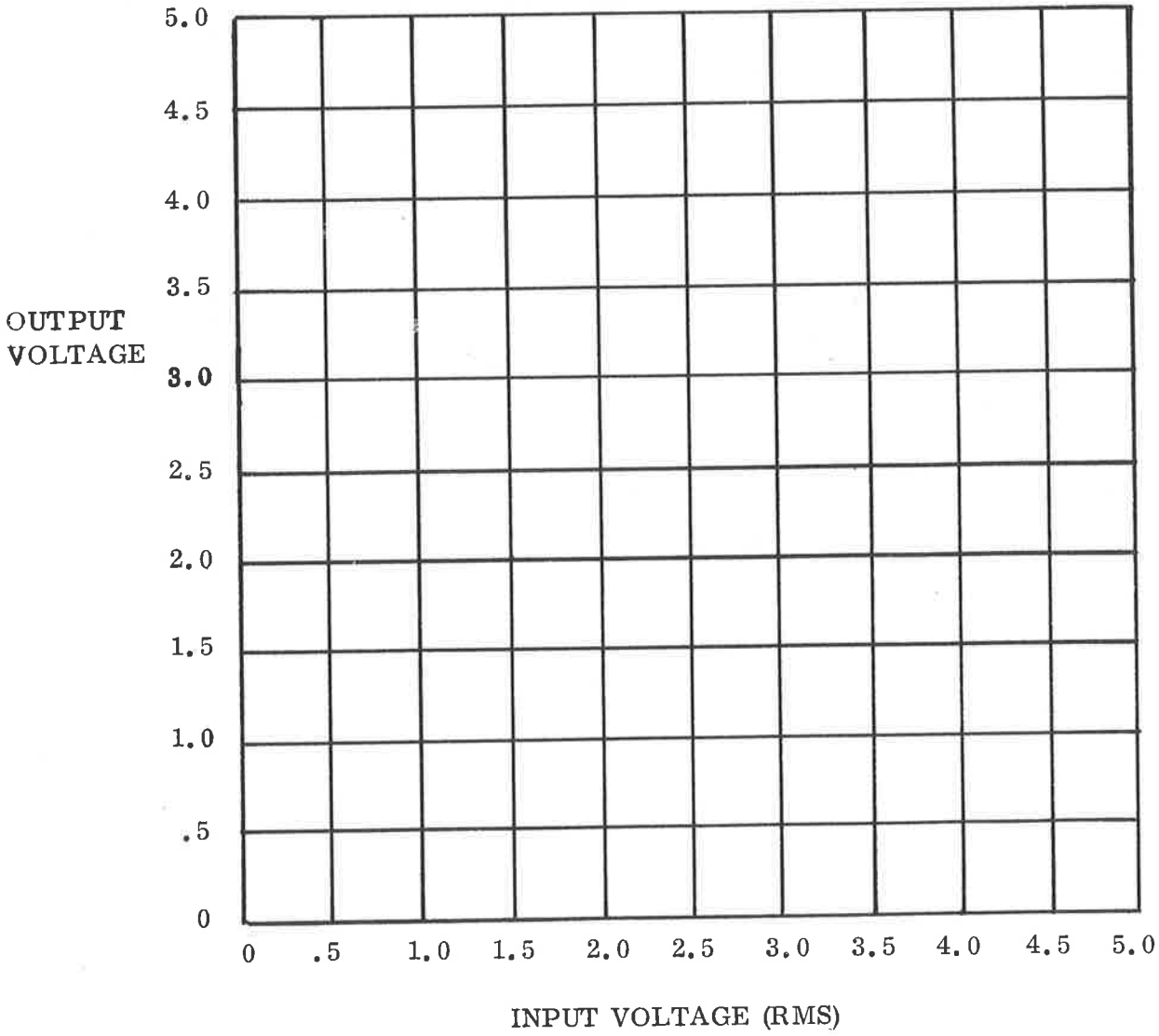
8. Adjust the 1K input pot to achieve a Reading of 5 volts RMS on the A.C. Meter connected to the Input.

9. Adjust the 100K pot to produce full scale (5 volts) on the Ed-Lab 650 meter.

10. Set the input voltage at the levels indicated in the table below and record the Output Voltage.

V_{in} EXTERNAL DMM RMS volts	V_{out} Ed-Lab 650 METER RMS volts
0	
0.1	
0.2	
0.5	
1.0	
2.0	
3.0	
4.0	
5.0	

11. Plot Input Voltage Versus Output Voltage on the Graph



QUESTIONS:

1. Is the curve linear?
2. Could this circuit be used in a practical A.C. Meter?
3. What is the maximum A.C. voltage that can be measured using this circuit?

Ed-Lab	ASTABLE OPERATION	EXP. NO. 16 Page No. 1

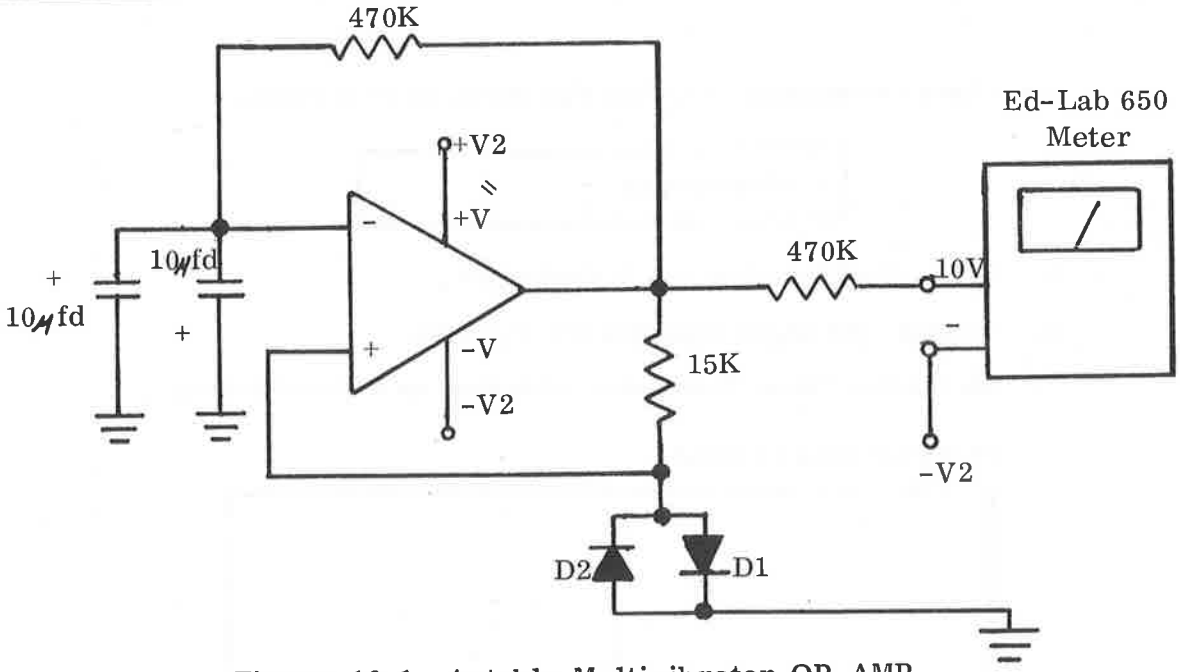


Figure 16-1 Astable Multivibrator OP-AMP

OBJECTIVE:

To use an OP-AMP as the Active element in an Astable Multivibrator or Square Wave Oscillator.

DESCRIPTION:

The Astable Multivibrator is an Oscillator which produces a Square Wave signal.

Figure 16-1 is an Astable Multivibrator OP-AMP circuit. The operation is as follows.

Assume that the output voltage is full Positive. Then the Non-Inverting Input to the OP-AMP will be a small positive voltage, one diode voltage drop above ground caused by D1. The 10ufd capacitor will begin to charge toward a Positive Voltage through the 470K feedback resistor. When the Capacitor Voltage exceeds the Voltage into the Non-Inverting input the Op-Amp output will swing to full negative. The Negative Output Voltage will set the Non-Inverting Input at one diode voltage drop below ground. The 10ufd capacitors will now charge toward a negative voltage and, when the capacitor voltage is more negative than the Non-Inverting input voltage the output Voltage switches back to Positive and the cycle repeats itself.

PROCEDURE:

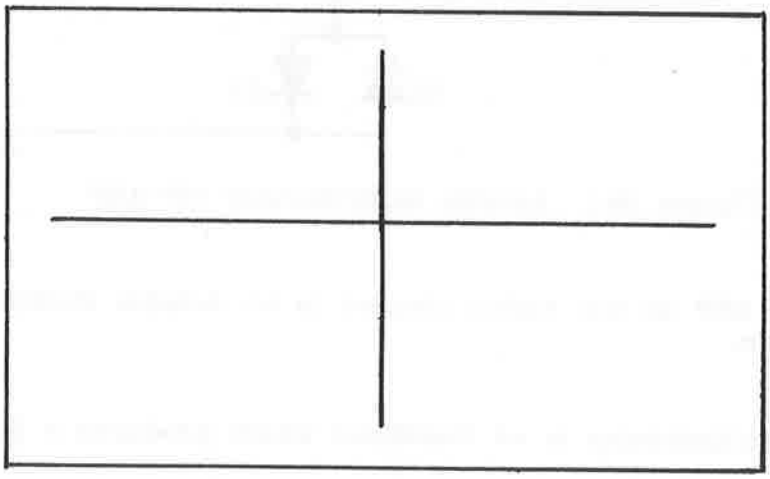
1. Wire the circuit shown in Figure 16-1.
2. Observe the Meter. The circuit should be slowly Oscillating.
3. Does the circuit oscillate?

4. Count the number of cycles that occur in 60 seconds.

Cycles/minute =

5. Connect an Oscilloscope to the Output.
6. Change the 10μfd capacitors to 0.01μfd.
7. Sketch the Output Waveform observed on the oscilloscope.

OUTPUT WAVEFORM



8. Record the Signal Period and Amplitude

Period =
Amplitude =

QUESTIONS:

1. Which components in this circuit will change the frequency of oscillation?

2. Would the circuit work if the two diodes D1 and D2 were replaced with two 1K resistors?

Ed-Lab	BISTABLE OP-AMP	EXP. NO. 17 Page No. 1

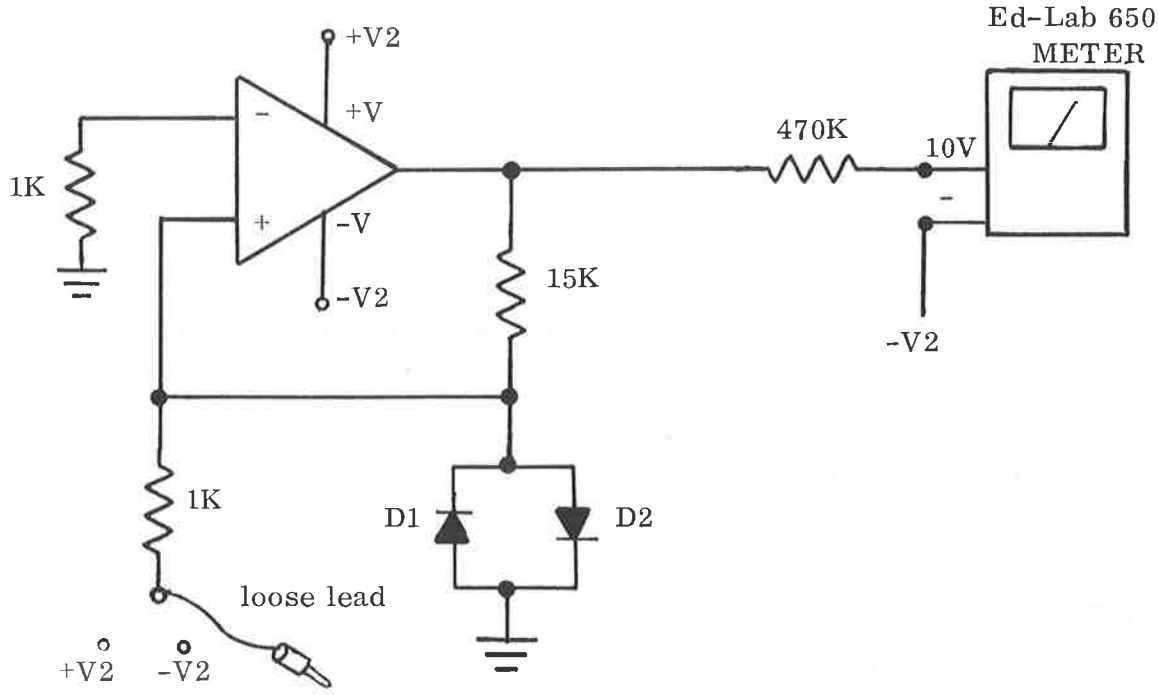


Figure 17-1 BISTABLE OP-AMP

OBJECTIVE:

To use an OP-AMP to fabricate a BISTABLE MULTIVIBRATOR and to test the circuit operation.

DESCRIPTION:

The Bi-Stable Multivibrator or One-Shot produces a single pulse each time the input trigger is activated.

This circuit is very similar to the circuit tested in experiment No. 16 the Astable OP-AMP. The Variation is that the Negative Feedback is eliminated and the Inverting input is connected to ground.

When the loose lead is touched to +V2 the output will be driven to full positive.

This positive Output Voltage will generate a small positive voltage across the Diodes D1 and D2.

When the loose lead is removed from +V2 the OP-AMP will remain a full positive output voltage because of the positive feedback to the Non-Inverting Input.

If the loose lead is momentarily touched to -V2 the reverse process will occur and the output will be negative.

PROCEDURE:

1. Wire the circuit shown in Figure 17-1.
2. Momentarily Touch the Loose Lead to +V2 and Remove. Record the Output Voltage

V_{out} (TOUCH +V2) = _____

3. Momentarily touch the loose lead to -V2 and remove. Record the output voltage.

V_{out} (Touch -V2) = _____

Note: The meter - is connected to -V2 and the scale is approximately 35 volts full scale so 0 volts on the meter is -V2, 3 volts on the meter is approximately +V2 or +10 volts.

4. Does the circuit operate properly?

5. Why is the circuit called BISTABLE?

QUESTIONS:

1. Does this circuit use Positive or Negative feedback?

Ed-Lab	VOLTAGE TO CURRENT AMPLIFIER	EXP. NO. 18 Page No. 1

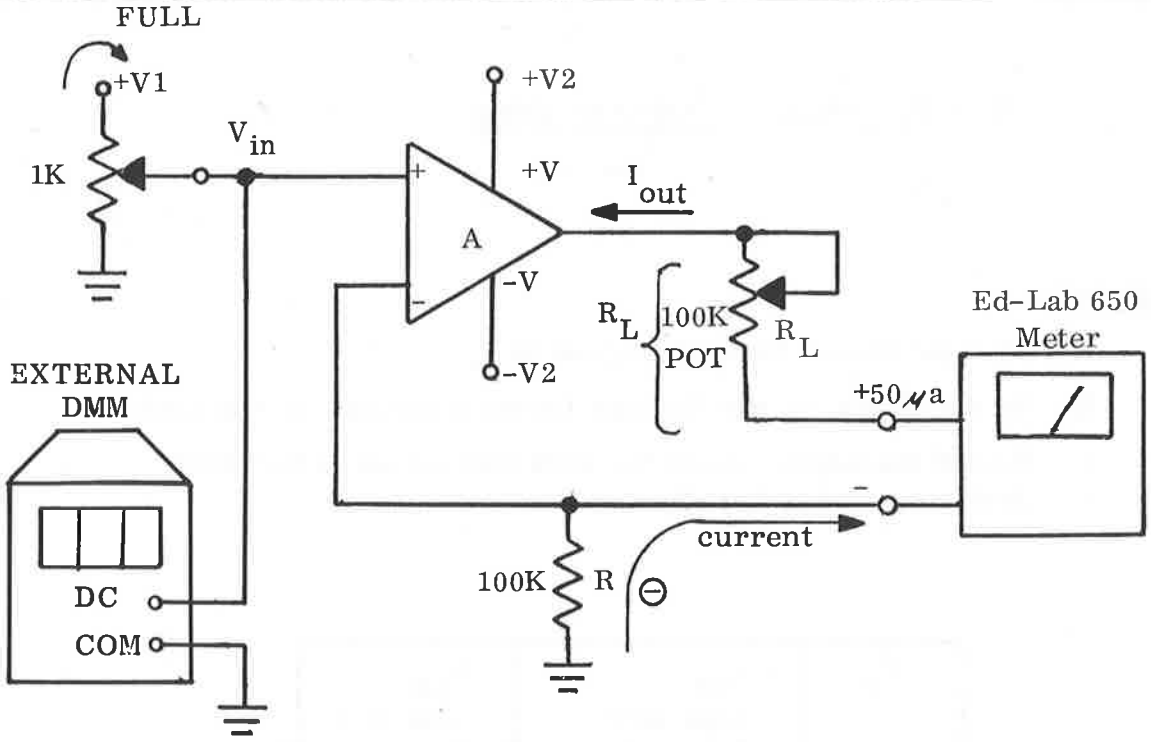


Figure 18-1 Voltage to Current Amplifier

OBJECTIVE:

To build and test a Voltage to Current Converter.

DESCRIPTION:

This circuit generates an output Current proportional to the input Voltage.

The Non-Inverting Input Voltage is set by the 1K V_{in} Pot. Feedback via the 100K pot and the Current Meter to the Inverting Input allows the circuit to maintain the Inverting Input at the same voltage as the Non-Inverting Input.

Since the Non-Inverting input draws no current, the output current is equal to V_{in}/R and the circuit converts input voltage to a current proportional to the Input Voltage.

Variations in the load resistance R_L will not effect the Output Current. For the circuit shown in Figure 18-1 the current is:

$$I_{out} = \frac{V_{in}}{R} = \frac{V_{in}}{100K} = (V_{in})\ (10ua)$$

This Output Current to Input Voltage relationship will be true until the value of R_L exceeds the value which requires full Op-Amp Output voltage to maintain the desired output current.

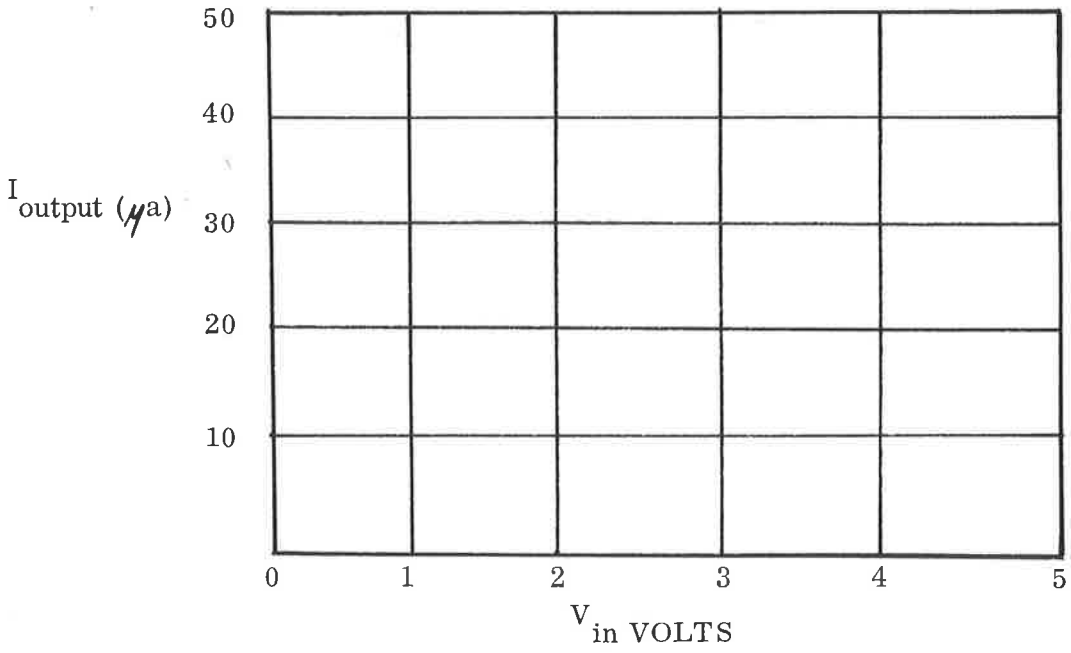
$$R + R_L \text{ (Max)} = \frac{V_{\text{OP-AMP (Max)}}}{I_{out}}$$

PROCEDURE:

1. Wire the Circuit Shown in Figure 18-1.
2. Set the 1K pot to the Voltage Levels indicated in the table
3. Record the output current for 100K load pot set at both full Resistance and at Zero Resistance.

V_{in}	I_{out} 100K POT ZERO OHMS	I_{out} 100K POT To 100K
0		
1		
2		
3		
4		
5		

4. Plot Input Voltage versus Output Current.



5. Is the curve linear for the low resistance of the Pot?

6. Calculate the Maximum I_{out} for the 100K load Pot setting?

$$I_{out}\ (MAX) = \frac{V_{OP\ AMP\ (MAX)}}{202K} = \frac{9.5}{202K} = 47\mu a$$

7. Does the Output Current Curve fall out of linearity in the range of the current calculated in step 6.

QUESTIONS:

1. What is the input impedance of this circuit?

Ed-Lab	CURRENT AMPLIFIER	EXP. NO. 19 Page No. 1

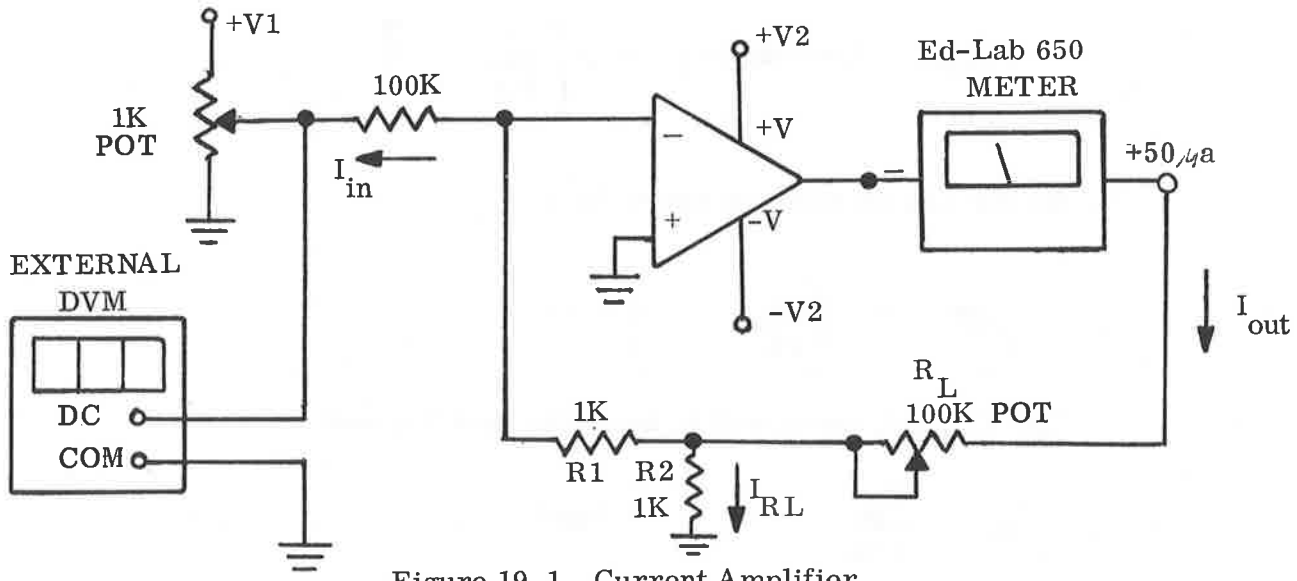


Figure 19-1 Current Amplifier

OBJECTIVE:

To build and test an OP-AMP Current Amplifier.

DESCRIPTION:

Figure 19-1 shows a Current Amplifier. The Output Current is proportional to the Input Current. Since the system has negative feedback the voltage at the Inverting Input will be zero. I_{in} will flow in R1. The voltage across R2 will be:

$$V_{R2} = - I_{in} \; R1$$

The current in R2 will be

$$I_{R2} = \frac{- I_{in} \; R1}{R2}$$

$$I_{out} = I_{R2} + I_{in}$$

$$I_{out} = \frac{- I_{in} \; R1}{R2} + I_{in}$$

$$I_{out} = -I_{in} \left[\frac{R1}{R2} + 1 \right]$$

$$\frac{I_{out}}{I_{in}} = \text{Current Gain} = -\left[\frac{R1}{R2} + 1\right]$$

for the circuit shown in figure 20-1

$$\frac{I_{out}}{I_{in}} = -\left[\frac{1K}{1K} + 1\right] = -2$$

The Output Current will be twice the Input Current.

$$I_{in} = \frac{V_{in}}{100K} = V_{in} \quad (10\mu a)$$

$$I_{out} = V_{in} \times 2 \times 10\mu a = I_{in} \times 2$$

PROCEDURE:

1. Wire the circuit shown in figure 19-1.
2. Set the V_{in} at the Values indicated in the Table. Record the Output Current for the 100K pot set at full and for the 100K pot set at zero.

V_{in}	$I_{in} = V_{in} \times 10\mu a$	I_{out} 100K Pot Zero	I_{out} 100K Pot Full
0	0μa		
0.5	5μa		
1	10μa		
1.5	15μa		
2	20μa		
2.5	25μa		

3. Calculate the Current Gain for the input of 10μa using the Data in the table of step 2.

$$\text{Current Gain} = \frac{I_{out}}{I_{in}} = \frac{(\quad)}{10\mu a} =$$

4. Calculate the Theoretical Current Gain

$$\text{Theoretical Current Gain} = \frac{R2}{R1} + 1 = \frac{1K}{1K} + 1 =$$

5. Do the Measured and Theoretical Current Gains agree?

6. Is the Output Current effected by the 100K resistance in the load?

QUESTIONS:

1. Why is this circuit called a Current Amplifier?
2. What is the Input Impedance of the Current Amplifier?
3. Which component could be changed to increase the Current Gain of the Amplifier?

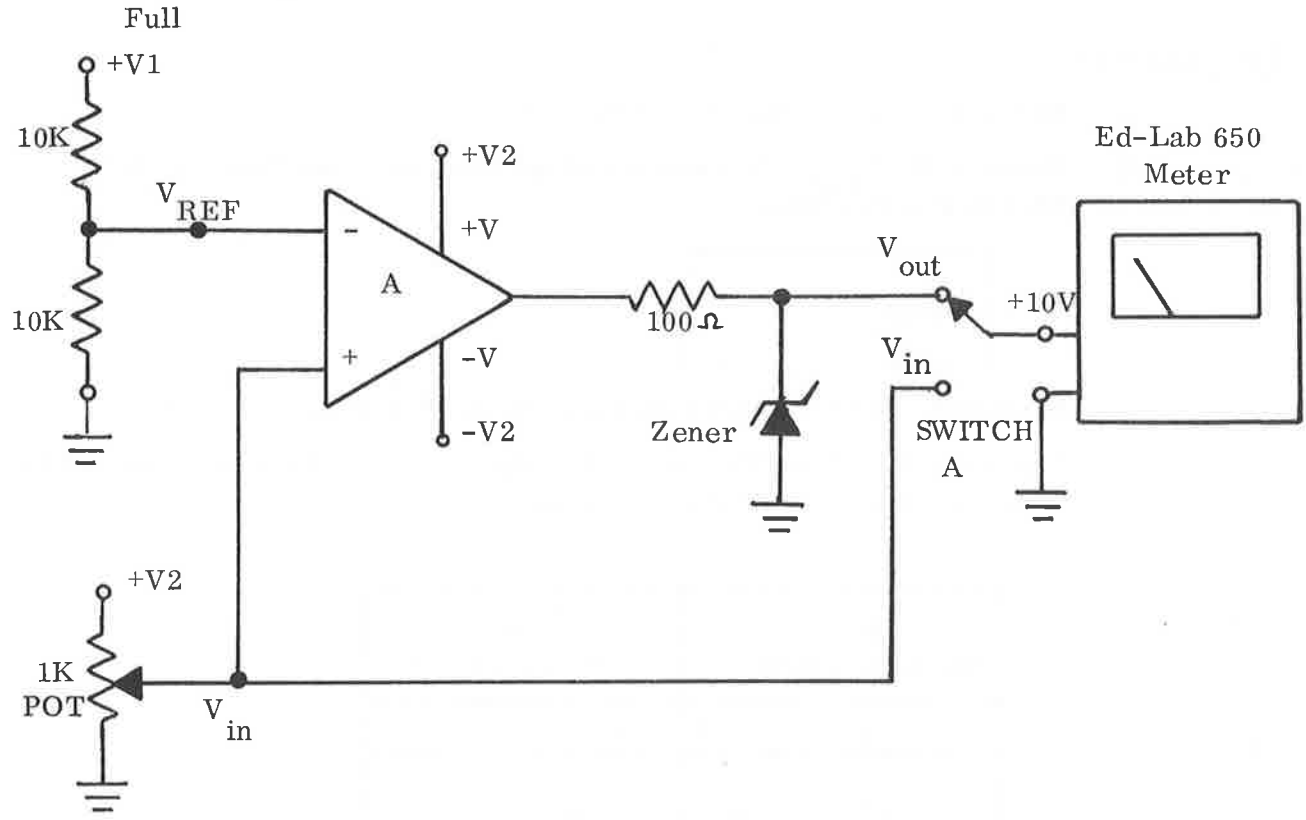


Figure 20-1 Voltage Comparator

OBJECTIVE:

To build and test an OP-AMP comparator.

DESCRIPTION:

The purpose of a Voltage Comparator is to compare an input voltage to a reference voltage. When the input voltage is LESS than the Reference Voltage the Comparators output will be Zero volts (ground). When the Input Voltage is GREATER than the Reference the Comparators output will be a Logic 1 of approximately 4 volts.

The Reference Voltage is applied to the OP-AMP Inverting Input. This is a constant D.C. voltage of 1/2 V1 set by the 10K voltage divider circuit.

The Input Voltage is applied to the Non-Inverting input and when the Input Voltage is greater than the Reference Voltage the OP-AMP output will swing to full Positive.

The Output circuit is current limited with a 100 ohm series resistor and voltage limited to the Zener Voltage. When the OP-AMP output is negative the Zener diode is forward biased and the V_{out} is clamped to one diode drop below ground.

PROCEDURE:

1. Wire the circuit shown in Figure 20-1.
2. Measure the V_{REF} Reference Voltage using the lead from the +10V Ed-Lab Meter input.

V_{REF} =

3. Reconnect the +10V input meter lead to the Switch A.
4. Adjust the V_{in} Input Voltage to the values listed in the table. Record the Output voltage for each Input Voltage.

V_{in} SWITCH A DOWN	V_{out} SWITCH A UP
0	
1	
2	
3	
4	
5	
6	
7	

5. Does the circuit output change?
6. Between which Input Voltages does the Output Voltage Switch?
7. Turn the 1K pot to the position for $V_{in} = 0$
8. Monitor the Output Voltage(SWITCH A UP)
9. Slowly Increase V_{in} (1K Pot) until the exact point where the Output voltage switches to 4 volts. Stop at this point.

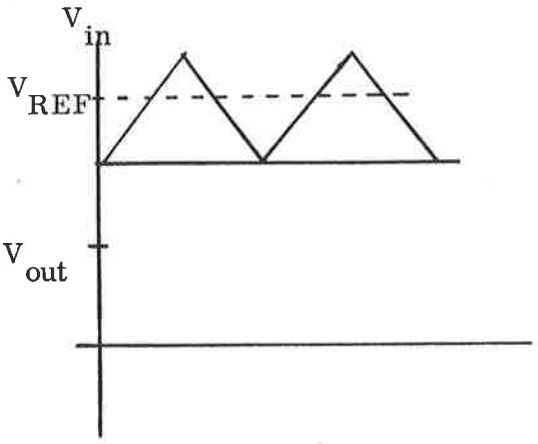
10. Place SWITCH A DOWN. Record the V_{in} at the Comparator Switching Point

V_{in} (SWITCHING POINT) =

11. How does the V_{in} at the Switching Point compare to the V_{REF} measured in step 2?

QUESTIONS:

1. What would the output waveform of a comparator look like if a Triangle wave of amplitude greater than V_{REF} were applied to the input? Sketch the output waveform below:



Ed-Lab	SCHMITT TRIGGER COMPARATOR	EXP. NO. 21 Page No. 1

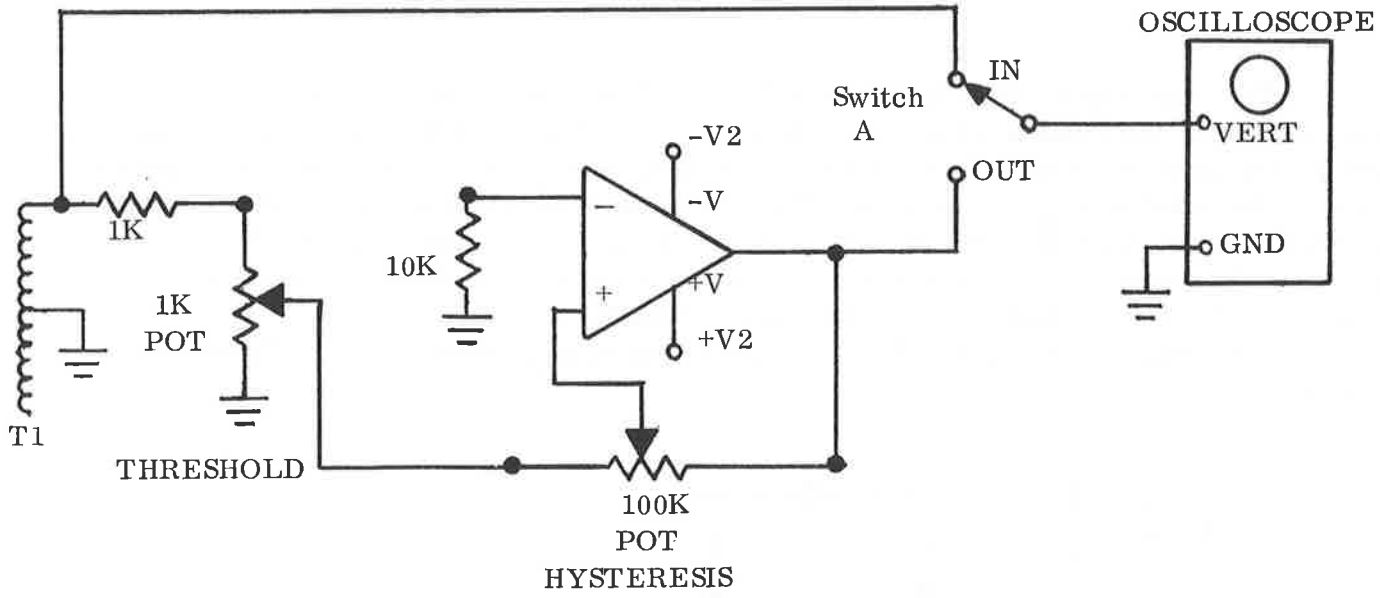


Figure 21-1 Schmitt Trigger Comparator

OBJECTIVE:

To build and test a Schmitt Trigger Comparator Circuit

DESCRIPTION:

The Schmitt Trigger Comparator is a Comparator circuit similar to the circuit of Experiment No. 20. The difference is that the input voltage required to turn the Comparator ON is higher than the Input Level required to turn the Comparator OFF. This creates a Dead Band of Input Voltages where the Comparator will not switch. The purpose of this feature is to make the circuit immune to noise on the input.

Figure 21-2 shows the SWITCHING POINTS of the Comparator for a noisy, slowly varying input voltage.

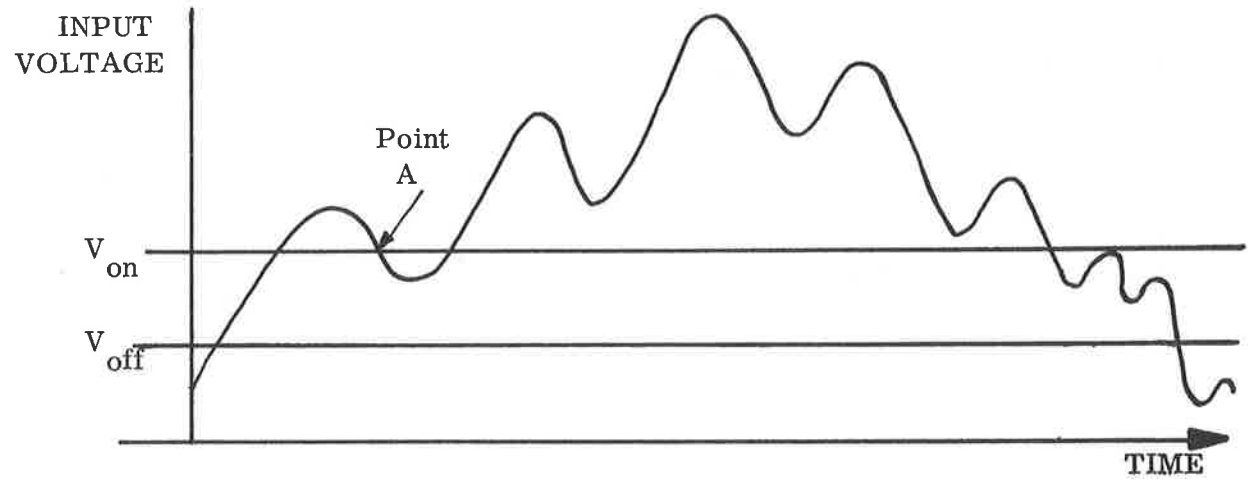


Figure 21-2 Schmitt Trigger Comparator Input Voltage

The noisy input signal turns the Schmitt Trigger comparator ON at V_{on}. A short time after this the input level drops below the V_{on} level due to noise, indicated as point A. This noise does not switch the Comparator again because it is not large enough to put the input voltage below V_{off}. Therefore, the circuit does not react to the small noise variations and will be turned ON and OFF by the Large Variations of the input signal only. This prevents the Output signal from turning on and off rapidly in response to the noise on the input signal when the input signal is near the switching point.

Figure 21-3 shows the Schmitt Trigger Comparator Output Voltage Versus Input Voltage.

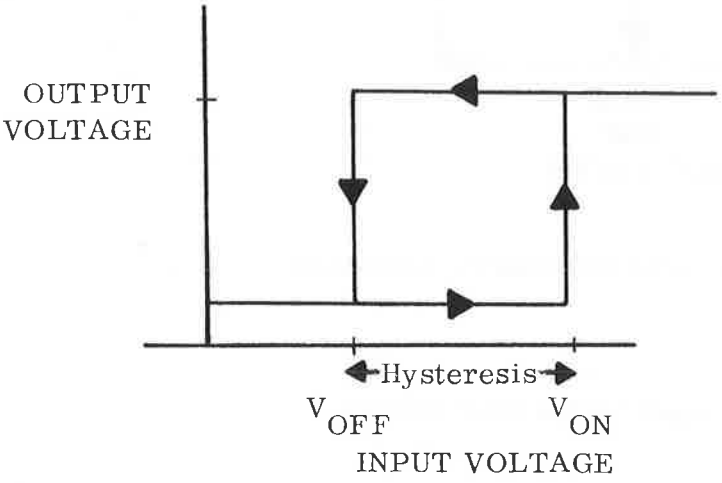


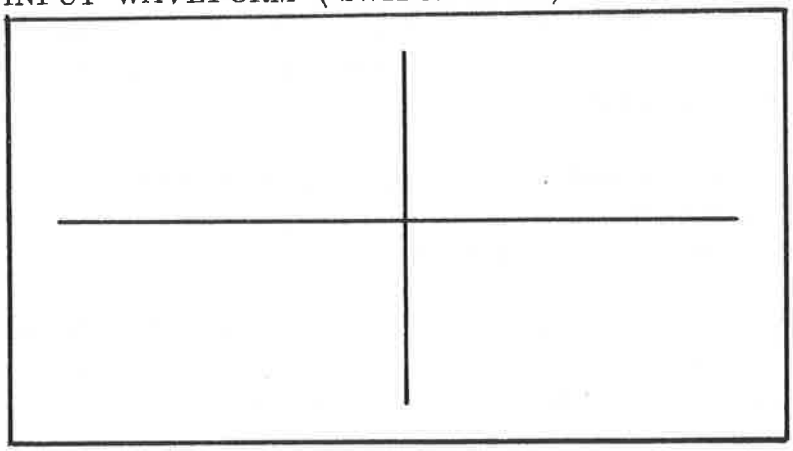
Figure 21-3 INPUT VERSUS OUTPUT VOLTAGE

The difference between the V_{OFF} and V_{ON} input voltages is called Hysteresis. In Figure 21-1 the Transformer output and the 1K pot generate an adjustable input A.C. Voltage. The 100K pot provides variable Positive feedback in the circuit to switch the Output when the threshold is reached. The setting of the 100K pot will determine the Hysteresis of the Input Voltage.

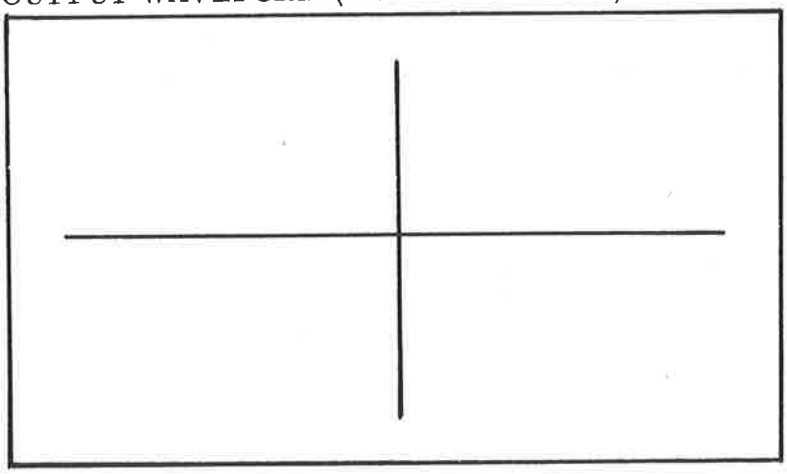
PROCEDURE:

1. Wire the circuit shown in Figure 21-1
2. Set the 1K pot for full voltage (away from the ground).
3. Adjust the 100K pot until the Output Signal is a Square Wave, (about 1/3 of full pot rotation).
4. Sketch the Input Waveform and the Output Waveform

INPUT WAVEFORM (SWITCH A UP)



OUTPUT WAVEFORM (SWITCH A DOWN)



5. Remove the Input and Output wires from switch A and connect in the circuit shown in Figure 21-4.

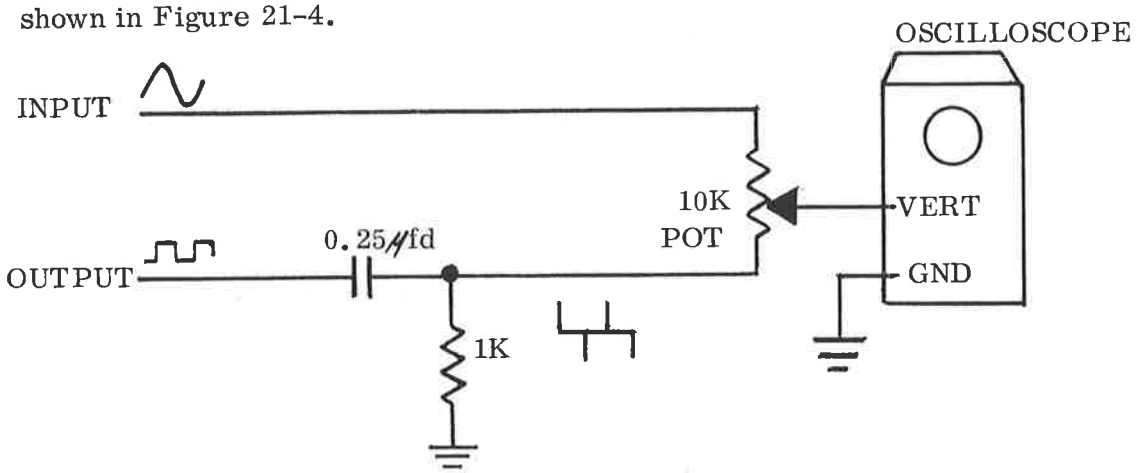


Figure 21-4 Switching Point Marker

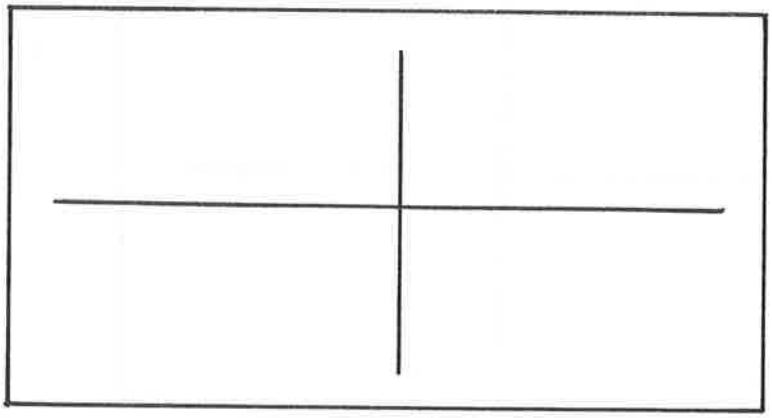
This circuit adds the Input Voltage to the switching spike generated by the Output Voltage. The Capacitor and 1K resistor act as a differentiator and generate a Positive going spike when the Comparator output turns ON and a negative going spike when the comparator turns OFF.

6. Adjust the 10K pot until the Waveforms seen on the oscilloscope shows the full A.C. Input Waveform with small positive and negative spikes to indicate the points at which the Comparator turns ON and OFF.

7. Turn the 100K pot and observe the Turn ON and Turn OFF points (spikes) on the Oscilloscope Waveform.
Describe the effect of Adjusting the 100K Hysteresis Pot.

8. Set the 100K Hysteresis Pot in the position where the Hysteresis voltage is easily seen. Sketch the waveform below:

WAVEFORM



Measure the Hysteresis Voltage (Voltage between Positive and Negative spikes).

$V_{Hysteresis}$ =

9. Adjust the 100K pot for Minimum Hysteresis. Record the minimum Hysteresis.

$V_{Hysteresis}$ (Minimum) =

10. Adjust the 100K Hysteresis pot for a large Hysteresis voltage.

11. Adjust the 1K Threshold Pot, note that a threshold may be achieved where the Comparator will not switch (spikes disappear).

    Can the Threshold be adjusted to be higher than the Input?_____

12. Disconnect the circuit of Figure 21-4. Connect the circuit shown in Figure 21-5.

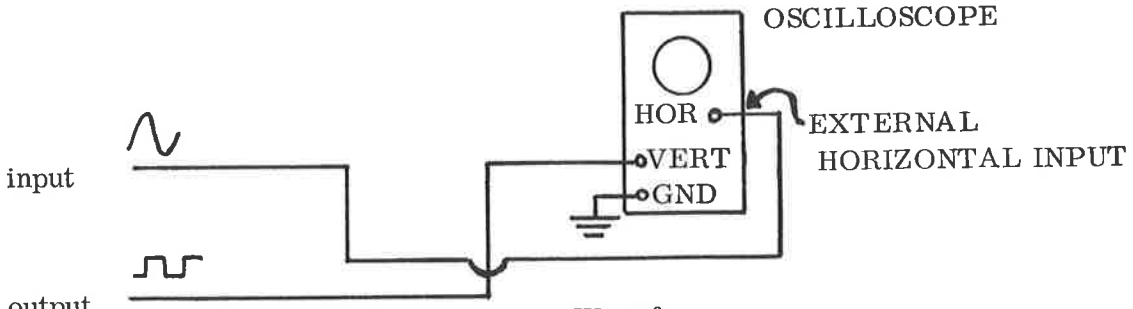
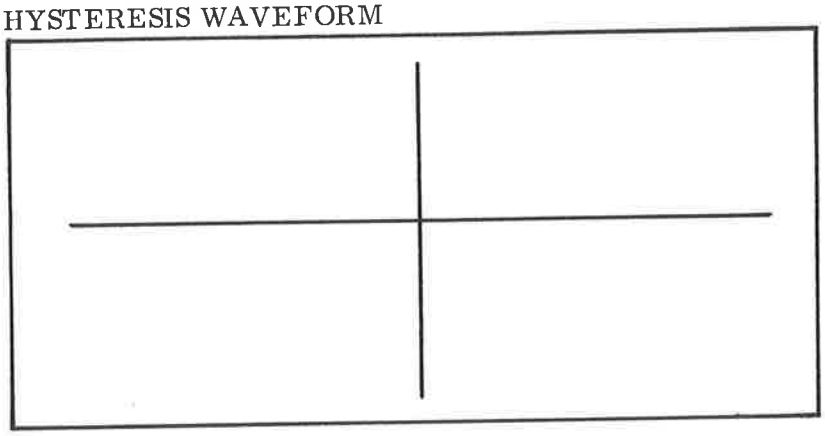


Figure 21-5 Hysteresis Waveform

13. Adjust the 100K Hysteresis pot and observe the Hysteresis of the Schmitt Trigger change. Set the Hysteresis at a convenient level.

14. Sketch the Waveform

HYSTERESIS WAVEFORM



15. Does the Waveform look like the one in Figure 21-3?

QUESTION:

1. Why do you suppose Schmitt Trigger Comparators are used in Large Industrial operations which use many electrical motors?

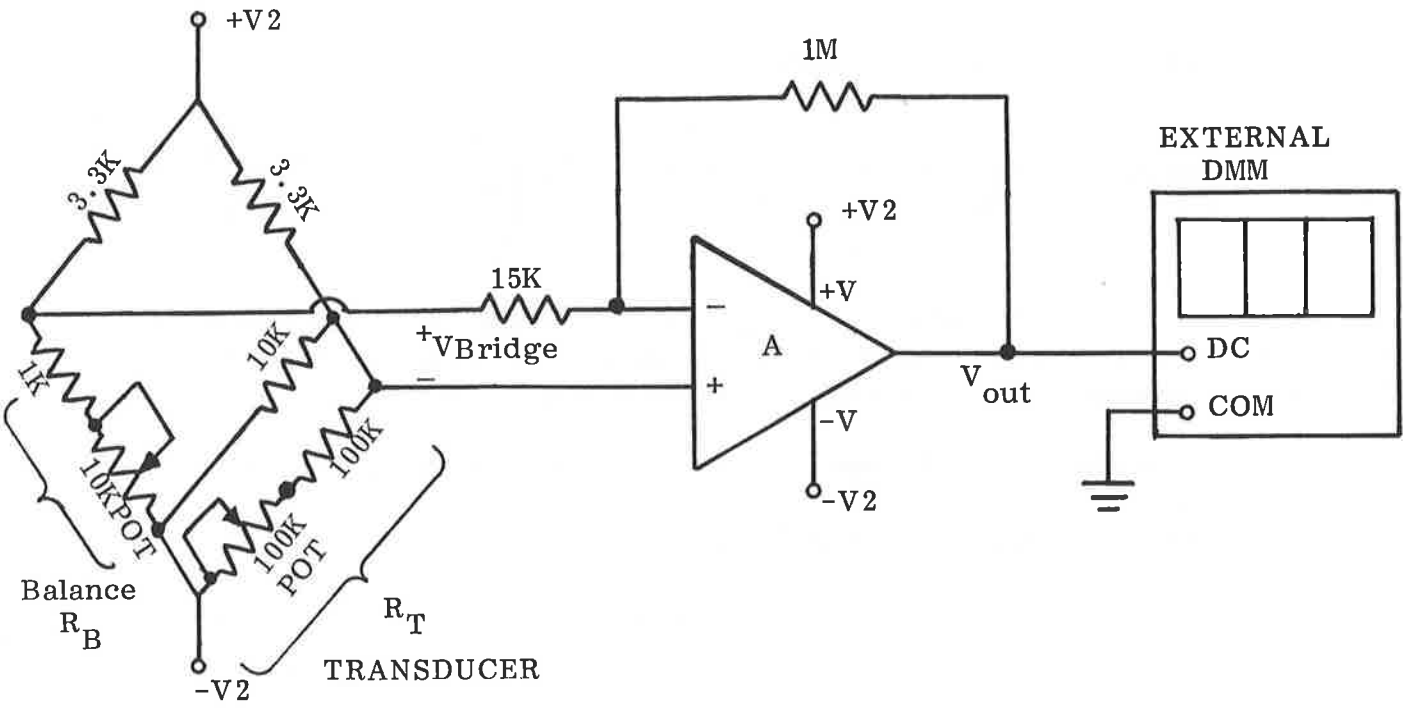


Figure 22-1 Instrumentation/Bridge Amplifier

OBJECTIVE:

To build and test a Bridge Transducer Circuit and to generate a Voltage output proportional to the Transducer Resistance Change.

DESCRIPTION:

Industrial Processes often need to convert physical quantities such as Temperature, Pressure, Flow, etc. into electrical signals which are used to control the process. Devices which are used to sense the physical quantities and generate electrical signals are called Transducers.

Many transducers react to physical changes by producing a small change in electrical resistance. These type of transducers include Themistors and Strain Gauges. When a transducer of this type is used it is often placed in a Balanced Bridge circuit, where the change in resistance generates a change in Bridge Output Voltage which is then amplified and scaled for use in a control circuit.

Figure 22-1 is a circuit of this type. The transducer unit is simulated with the 100K POT in parallel with the Transducer Bridge leg.- 10K resistor. The 100K resistor in series with the 100K pot assures that the overall change in Resistance of the Transducer leg will be small.

The Voltage Output of the Bridge is given by:

$$V_{BRIDGE} = \frac{V_2 \ R_B}{R_B + 3.3K} - \frac{V_2 \ R_T}{R_T + 3.3K} = V_2 \left[\frac{R_B}{R_B + 3.3K} - \frac{R_T}{R_T + 3.3K} \right]$$

R_B can be adjusted so the V_{BRIDGE} is Zero Volts. When this is done the Bridge is said to be balanced. After the Bridge has been balanced, variations in the Transducer Resistance will cause variations in the Bridge Output Voltage.

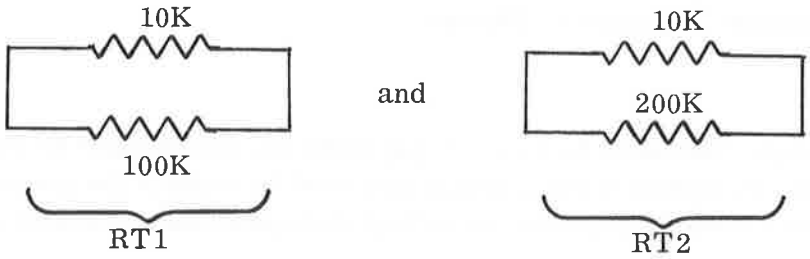
These variations in Bridge Voltage will be amplified by the OP-AMP and will generate a large Output Voltage swing.

The overall gain of the Amplifier is

$$G = \frac{-R_f}{R_{in}} = \frac{-1M}{15K} = -66.7$$

Note that the Amplifier gain is adjustable.

When the 100K Pot is adjusted to each of the two extreme limits of Rotation we are producing the following two Transducer Resistances.



$$R_T \ 1 = \frac{(10K)\ (100K)}{10K + 100K} = \frac{1000K}{110} = 9.09K$$

$$R_T \ 2 = \frac{10K \ (200K)}{10K + 200K} = \frac{2000K}{210} = 9.52K$$

The total R_T variations is

$$\Delta R_T = R_{T2} - R_{T1} = 9.52K - 9.09K = 0.43K = 430 \text{ ohms}$$

The Percent Variation in the Transducer leg is

$$\% \text{ Variation } R_T = \frac{0.43}{9.09} \times 100 = 4.7\%$$

This small variation in Resistance will cause a change in V_{BRIDGE} which is amplified and used as an Output Voltage

PROCEDURE:

1. Wire the circuit shown in Figure 22-1
2. Set the 100K Transducer Pot in the Center Position
3. Adjust the 10K Bridge Balance Pot for an output voltage of as close to zero as possible. Record the Output Voltage

V_{OUTPUT} (BALANCED) =

4. Turn the 100K pot to Zero Ohms Record the Output Voltage

V_{output} (100K POT = MIN) =

5. Turn the 100K pot to 100K ohms. Record the Output Voltage

V_{OUTPUT} (100K POT = FULL) =

6. Calculate the Output Voltage Variation produced by the change in R_T

$$\Delta V_{OUTPUT} = V_{OUTPUT} \text{ (100K POT = FULL)} - V_{OUTPUT} \text{ (100K POT = MIN)}$$

$$= (\quad) - (\quad) =$$

ΔV_{output} =

7. Calculate the Transducer Scale Factor in Volts/ohm

$$\text{Transducer Scale Factor} = \frac{\Delta V_{OUT}}{\Delta R_T} = \frac{(\quad)}{430} =$$

Transducer Scale Factor = volts/ohm

Note that using this system you can measure resistance variation as small as 1 ohm in a 10K resistor. This is a 0.01% variation measurement.

QUESTIONS:

1. What would the effect be if the 1 Meg feedback resistor were changed to 100K.

2. For an amplifier gain of - 66.7, what is the Bridge output voltage when the Amplifier Output is 1.0 volts?

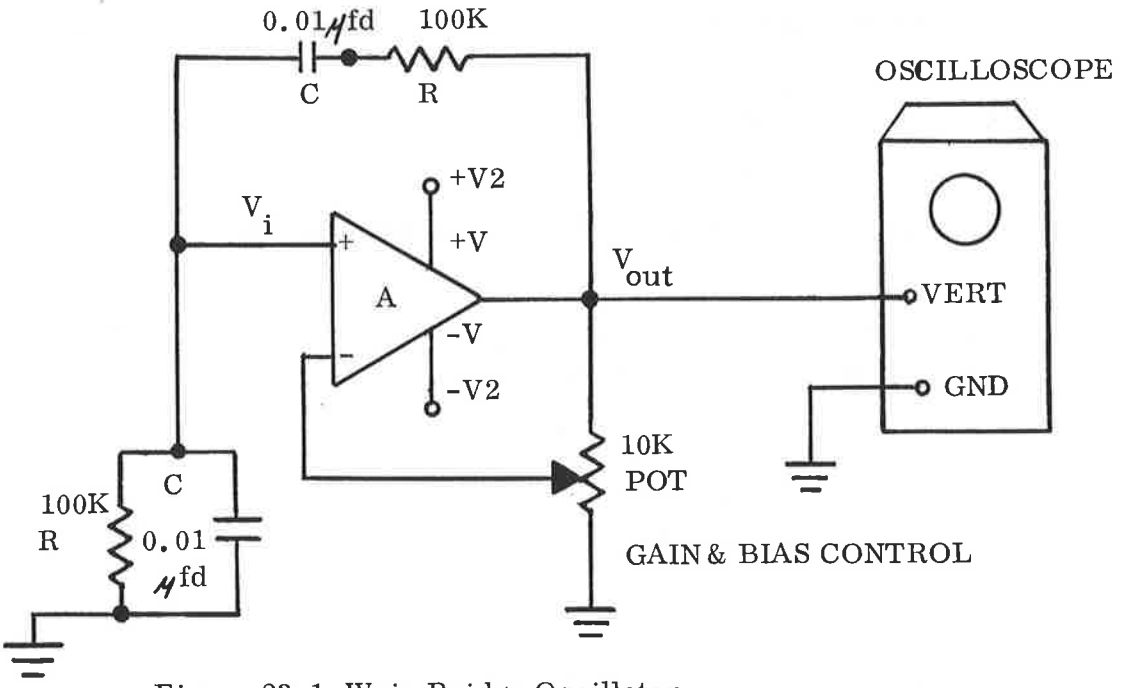


Figure 23-1 Wein Bridge Oscillator

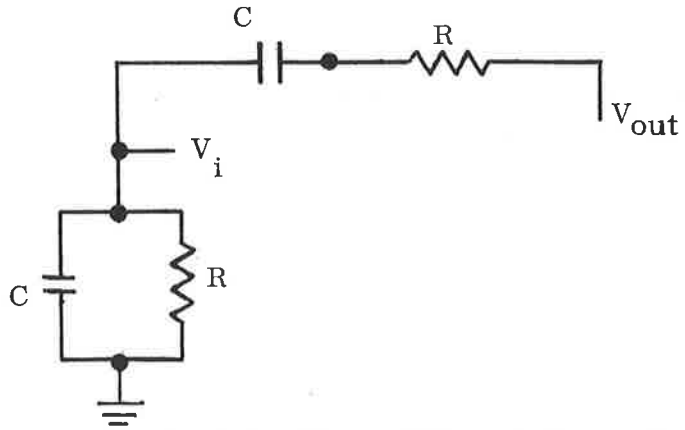
OBJECTIVE:

To build and test a WEIN BRIDGE OSCILLATOR.

DESCRIPTION:

The WEIN BRIDGE Oscillator uses Positive Feedback in an OP-AMP to generate sustained oscillation. Oscillation occurs when the feedback voltage to the amplifier Input (V_i) is in phase with the Output voltage.

For the circuit in Figure 23-1 the phase network in the Positive feedback loop looks like this:



The frequency at which the Phase of V_o and V_i are the same will be the frequency of Oscillation.

This occurs when

$$f = \frac{1}{2\pi RC}$$

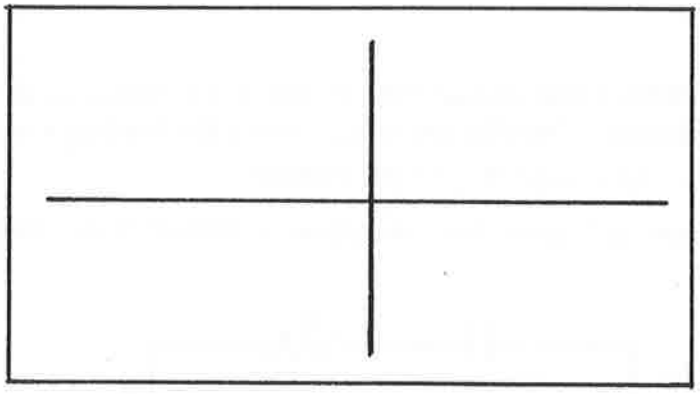
For the circuit values used in this experiment

$$f = \frac{1}{2\pi (100 \times 10^{3})\ (0.01 \times 10^{-6})} = \frac{1}{2\pi \times 10^{-3}} = 159\text{Hz}$$

f = 159 Hz

PROCEDURE:

1. Wire the circuit shown in Figure 23-1
2. Adjust the 10K GAIN & BIAS POT for a "clean" output waveform
3. Sketch the Output Waveform below:



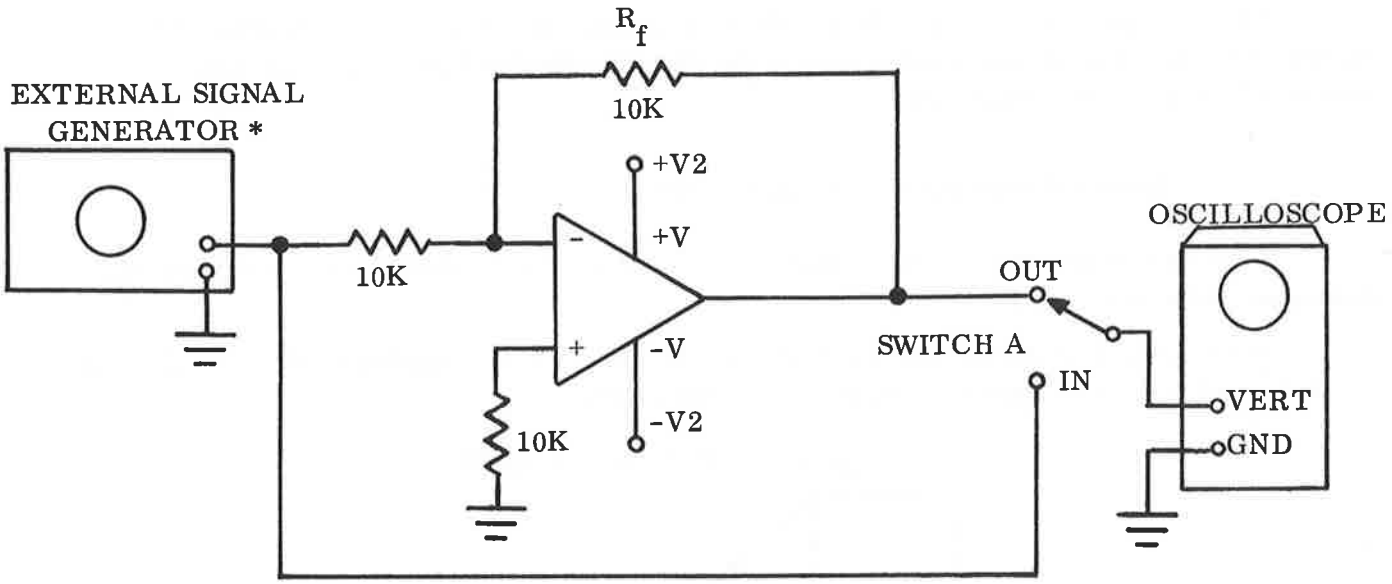
4. Calculate the Frequency

$$F = \frac{1}{P} =$$

QUESTIONS:

1. How does the Output Frequency compare with the Theoretical value of 159 Hz?
2. Which components will cause the frequency to change?

Ed-Lab	GAIN BANDWIDTH	EXP. NO. 24 Page No. 1



* Both Audio & R.F. Generators may be necessary to obtain all the frequencies needed.

Figure 24-1 Gain Bandwidth

OBJECTIVE:

To measure the frequency response of an OP-AMP Inverting Amplifier for various amplifier gain levels. The Gain Bandwidth Product will be plotted and calculated.

DESCRIPTION:

The Integrated Circuit Operational Amplifier has a 3db or half power frequency where the Amplifier gain is only half the D.C. value. This frequency is a function of the internal circuit of the Integrated Circuit. When the OP-AMP is used in a Negative Feedback Amplifier, the Overall circuit gain is reduced to a very small fraction of the Open Loop Amplifier Gain. In fact, the formula for the gain of the Inverting Amplifier, $-\frac{R_f}{R_{in}}$, assumes that the operational Amplifier gain is so high that it can be neglected. When the frequency of the input signal reaches a point where the OP-AMP gain is reduced by half, the gain is still high enough to be neglected in the formula. Therefore, if negative feedback is used, the overall gain of the negative feedback amplifier will not be reduced to half when the OP-AMP gain reduces to half. The use of negative feedback results in the half power frequency of the amplifier being extended beyond the half power frequency of the OP-AMP I.C.

The half power frequency of an OP-AMP circuit is called its Bandwidth. The Bandwidth times the circuit gain is called the Gain Bandwidth Product. This Gain Bandwidth Product is a constant

(Gain) (Bandwidth) = K (constant)

Note that if the Gain of the circuit is increased, the Bandwidth of the circuit will decrease and visa-versa.

If we were to calculate the Gain Versus frequency for a feedback OP-AMP Circuit for different values of gain we would obtain this graph.

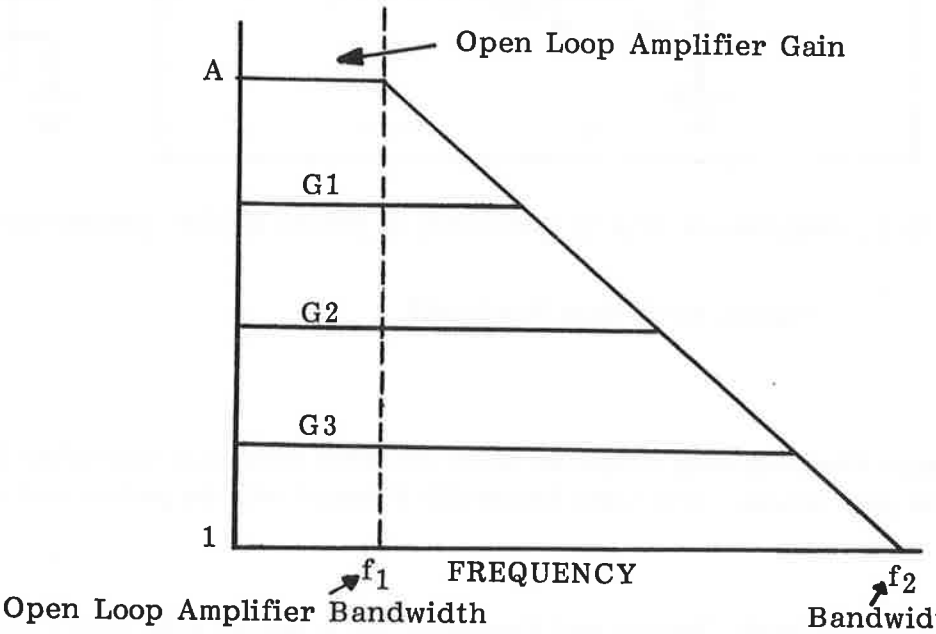


Figure 24-2 GAIN-BANDWIDTH PRODUCT CURVE

The curve shown in figure 24-2 shows the circuit bandwidth for various gain levels. The intersection of the horizontal Gain lines and the sloping Gain Bandwidth Product line to the right occur at the half power frequency for each level of gain.

Bandwidth (Unity Gain) = 1 MHz

This tells us that an amplifier circuit with a D.C. gain of 1 will reach half power gain of 0.707 at a frequency of 1 MHz.

In order to determine the Bandwidth of a circuit with a gain of 10 we must use this information.

1 MHz = 10 (Circuit Bandwidth)

$$\text{Circuit Bandwidth} = \frac{1\ \text{MHz}}{10} = 100\text{KHz}$$

Therefore a circuit with a gain of 10 would reach the half power point at 100 KHz.

PROCEDURE:

1. Wire the circuit shown in Figure 24-1.
2. Set the Signal Generator to the frequencies indicated in the Table below. Adjust the Signal Generator Amplitude for an undistorted output Signal and record the Input and output signal amplitudes. Change the value of R_f as indicated in the table.

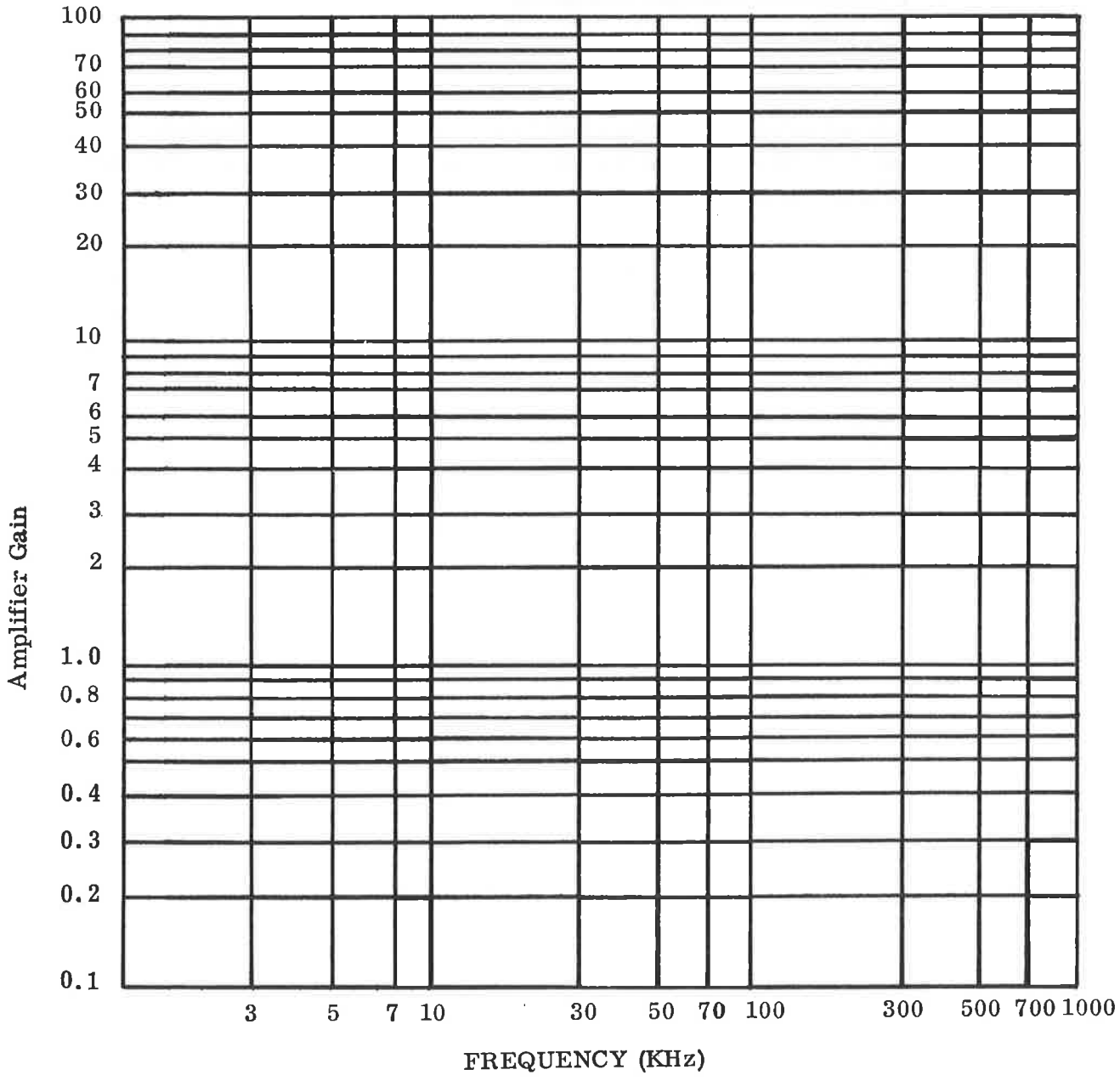
FREQ. Hz	R_f = 10 K Vout/Vin	R_f = 10K GAIN	R_f = 22K Vout/Vin	R_f = 22K GAIN	R_f = 33K Vout/Vin	R_f = 33K GAIN
5K						
7K						
10K						
30K						
50K						
70K						
100K						
300K						
500K						
700K						
1M						

Ed-Lab | GAIN BANDWIDTH | **EXP. NO.** 24 **Page No.** 4

FREQ. Hz	R_f = 56K Vout/Vin	R_f = 56K GAIN	R_f = 100K Vout/Vin	R_f = 100K GAIN	R_f = 470K Vout/Vin	R_f = 470K GAIN
5K						
7K						
10K						
30K						
50K						
70K						
100K						
300K						
500K						
700K						
1M						

3. Calculate the Gain (V_{out} / V_{in}) and enter in the columns of the table.

4. Plot the results in the graph below:



5. Calculate The Gain Bandwidth Product

   To find the Gain Bandwidth Product, note the highest possible gain achieved at 100 KHz and multiply this gain times 100 KHz.

   (G) (BW) = Gain (max @ 100 KHz) x 100 KHz

(G) (BW) =

6. If we desired to build an audio amplifier with a flat (3 db) frequency response to 70 KHz, what is the maximum gain we can achieve. Use the data in the curve of step 4.

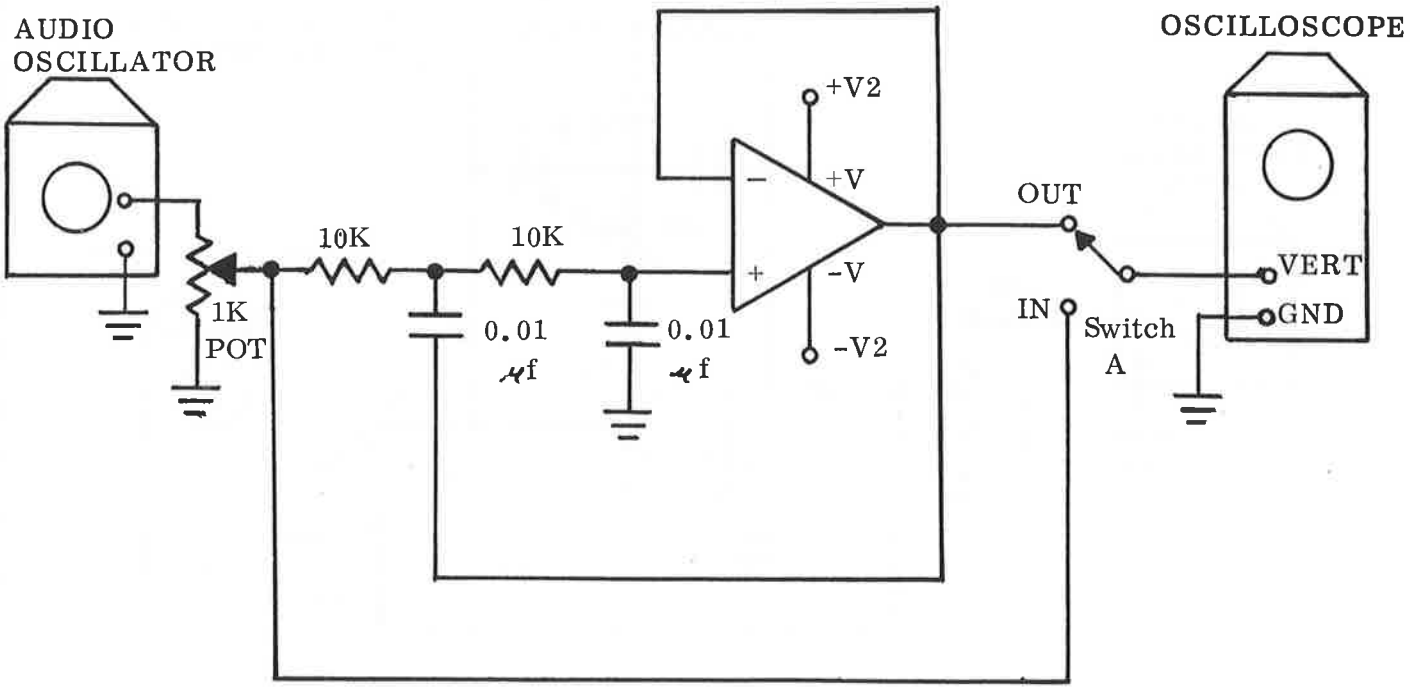


Figure 25-1 LOW PASS FILTER

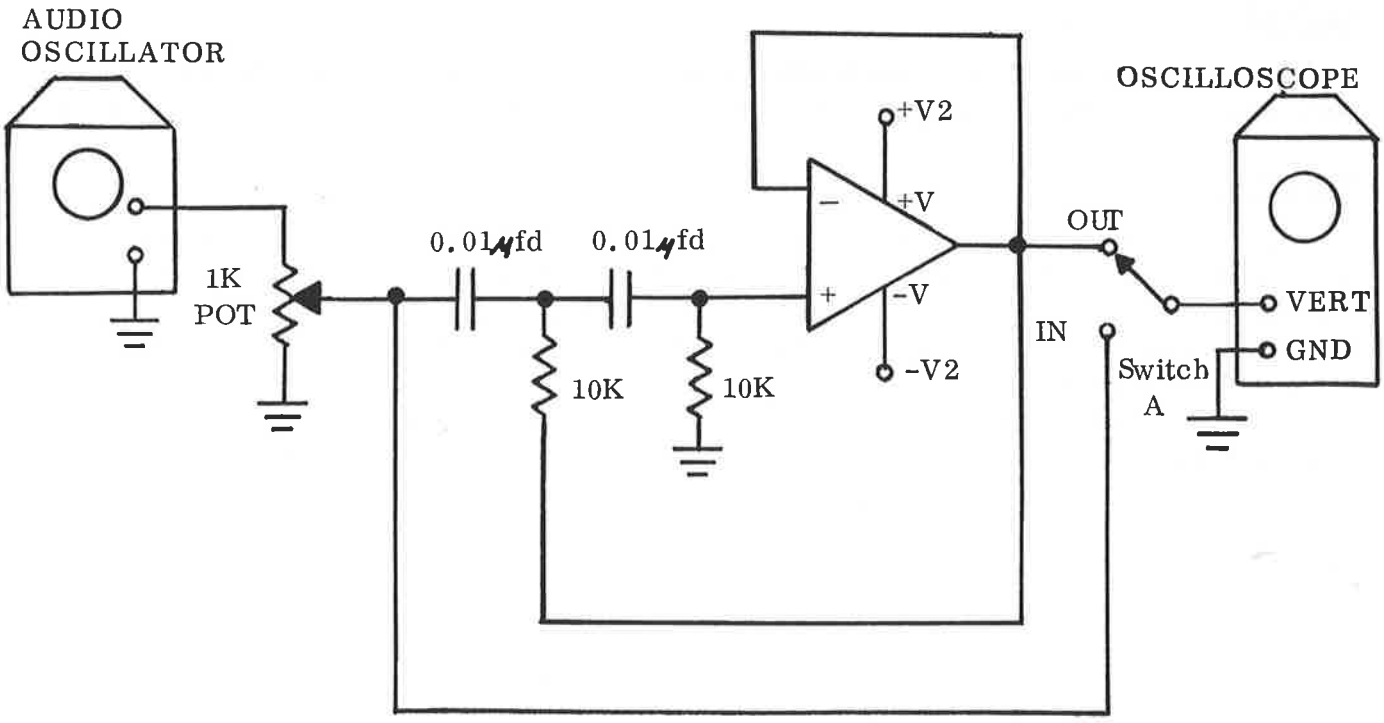


Figure 25-2 HIGH PASS FILTER

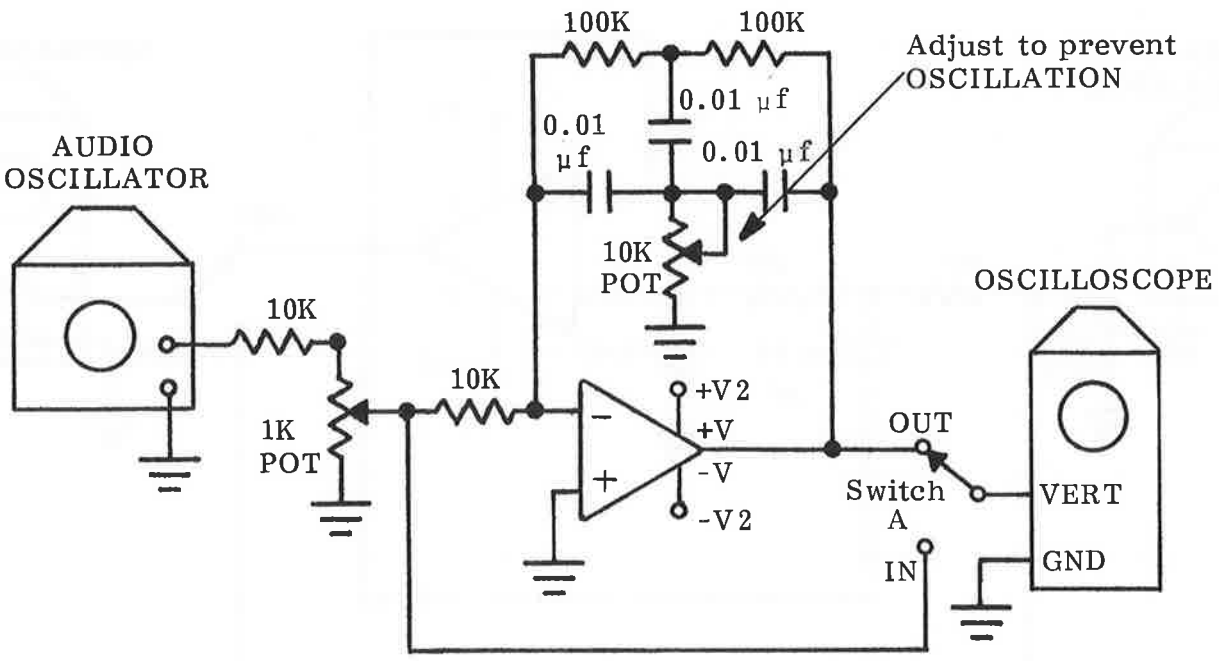


Figure 25-3 BAND-PASS FILTER

OBJECTIVE:

To use an Operational Amplifier to generate High Pass, Low Pass and Band-Pass Filter Responses and to measure the frequency response of each of the filters.

DESCRIPTION:

Three types of Active Filters are studied in this experiment, High Pass, Low Pass and Band-Pass. The circuits each employ an Operational Amplifier and Feedback, therefore they are called ACTIVE FILTERS. The use of an Amplifier and Feedback make the response of the filters much sharper than the response of only the passive filter elements.

The advantage of using Active Filters over simple passive elements is that improved filter response is achieved, filter attenuation is eliminated and the number of reactive elements required to produce the filter is reduced.

PROCEDURE:

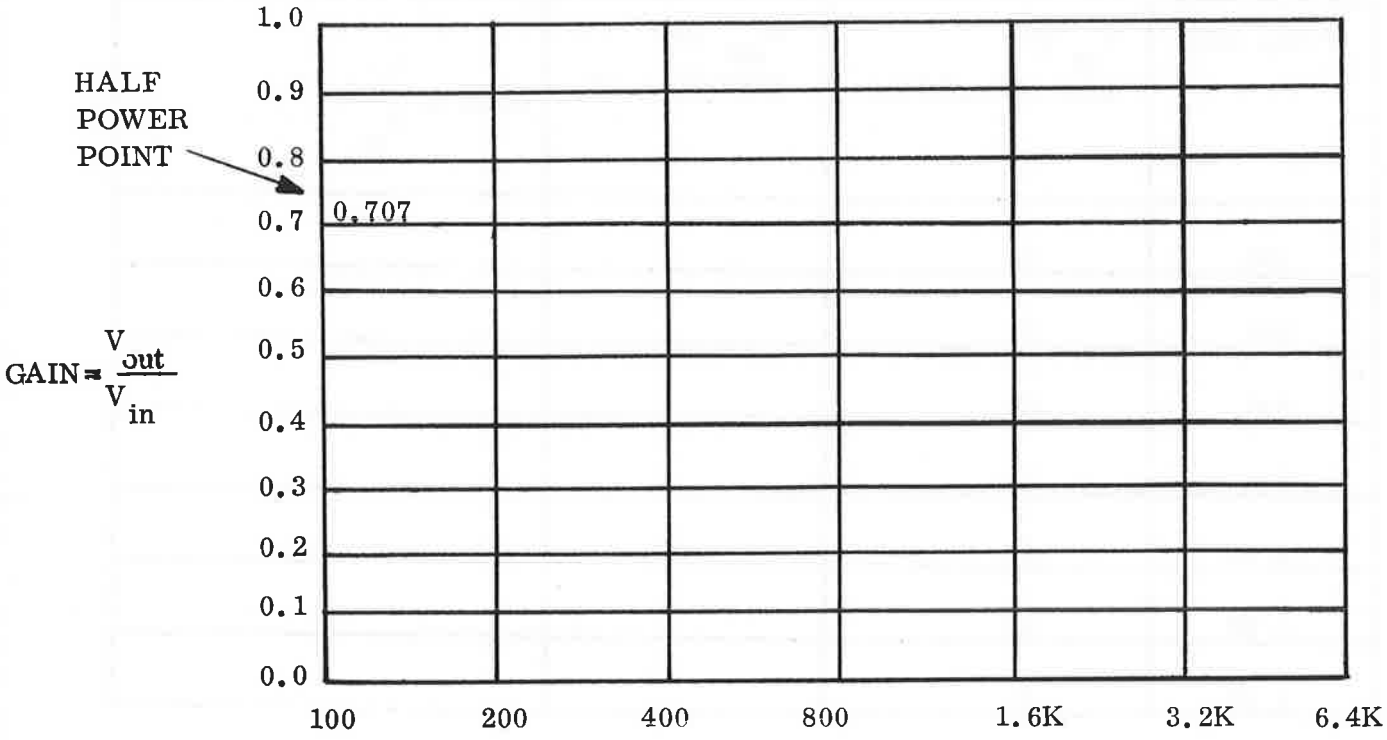
1. Wire the circuit shown in Figure 25-1.
2. Set the Audio Oscillator frequency to 100 Hz. Adjust the V_{in} amplitude for an undistorted output waveform (5 volts p-p). Record V_{in} and V_{out} for each of the frequencies in the table.

Freq. (Hz)	V_{in} p-p SWITCH A DOWN	V_{out} p-p SWITCH A UP	GAIN = $\frac{V_{out}}{V_{in}}$
100	5v		
200	5v		
400	5v		
800	5v		
1.6K	5v		
3.2K	5v		
6.4K	5v		

3. Calculate the GAIN for each frequency in the table.

$$\text{GAIN} = \frac{V_{out}}{V_{in}} = \frac{V_{out\ (p-p)}}{5}$$

4. Plot the Data on the graph below:



5. Mark the graph of step 4 at the point where the curve crosses the HALF POWER POINT.
Record the frequency at which this occurs.

freq. (HALF POWER POINT) =

6. The shape of the filter response curve can be described by the half power frequency found in step 5 and by the rate of decrease of the filter output voltage for frequencies above the half power frequency.
The half power frequency is called the "break" frequency or "3 dB point".
The rate of decrease above the break frequency is called the Rolloff and is expressed as dB per octave.

$$\text{Rolloff} = 20 \log \left[\frac{\text{GAIN at 3.2KHz}}{\text{GAIN at 6.4 KHz}} \right]$$

$$\text{Rolloff} = 20 \log \left[\frac{\qquad}{\qquad} \right] =$$

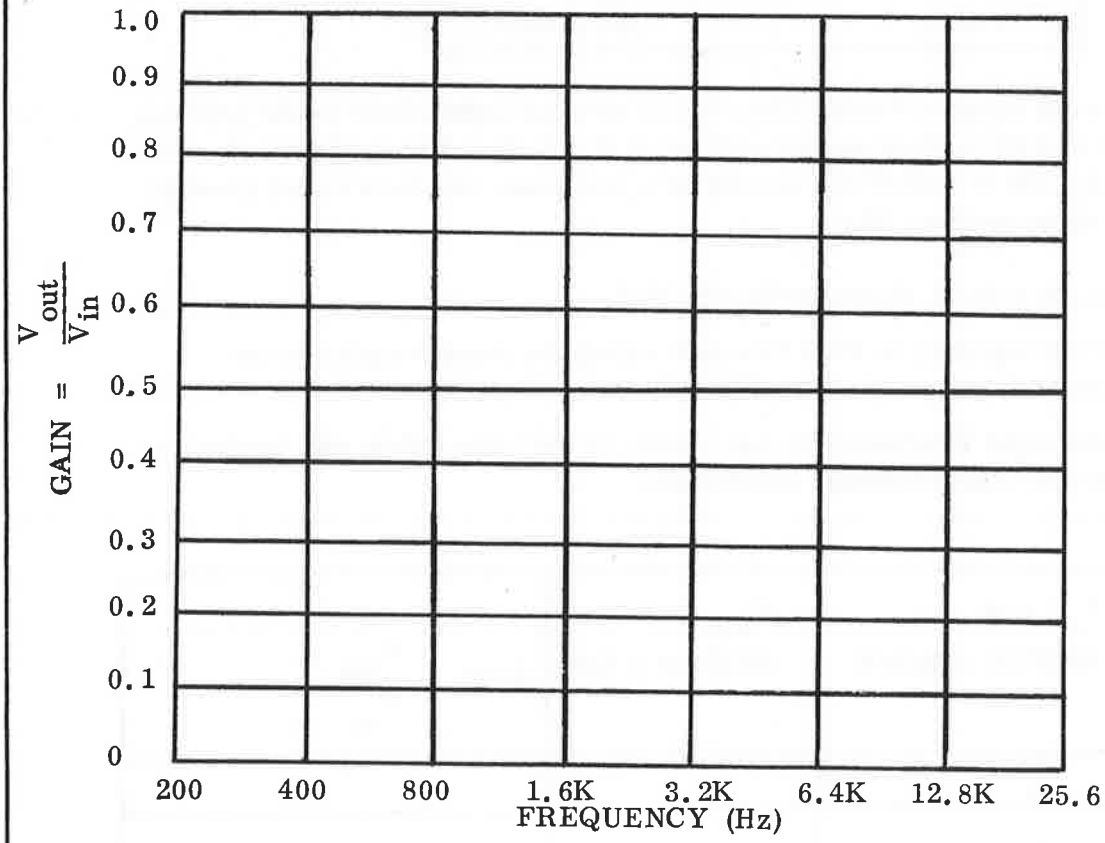
Rolloff =	dB/octave

Note that the passive 2 pole filter at the op-amp input alone would produce a Rolloff of 6 dB/octave so the addition of the Active Element provides an additional 6 dB of rolloff per octave or a decrease rate four times greater than the same passive filter.

7. Wire the circuit shown in figure 25-2.
8. Set the frequency at 25.6 KHz and adjust the Input Amplitude for undistorted output waveform (5 volts peak to peak).
9. Set the Input Frequency to each value in the table below and record the Input and Output voltage amplitudes.

Freq. (Hz)	V_{in} p-p SWITCH A DOWN	V_{out} p-p SWITCH A UP	GAIN = $\frac{V_{out}}{V_{in}}$
25.6K	5v		
12.8K	5v		
6.4K	5v		
3.2K	5v		
1.6K	5v		
800	5v		
400	5v		
200	5v		

10. Plot the data on the graph below:



11. Calculate the "Rolloff" in dB/octave

$$\text{"Rolloff"} = 20 \log \left[\frac{(\ \text{GAIN at 400 Hz}\ )}{(\ \text{GAIN at 200 Hz}\ )} \right]$$

$$\text{Rolloff} = 20 \log \frac{(\quad)}{(\quad)} = 20 \log (\quad) =$$

Rolloff =

Note that the Rolloff rate of the high pass filter is improved to the same degree that the low pass filter response was improved.

12. Wire the circuit shown in figure 25-3.
13. Set the 1K POT to Zero (no audio input). Adjust the 10K pot to the minimum level which does not permit Oscillation. For too large a setting of the 10K POT the circuit will oscillate and an output waveform will be observed with no audio signal applied.

14. Adjust the Audio Oscillator frequency and the 1K Amplitude pot until the largest undistorted output signal is obtained. Set the Input Amplitude to a convenient level smaller than the level which causes distortion.

15. Record the Frequency Input voltage and Output voltage at this resonant frequency.

Freq. (Resonance)=	V_{in} =	V_{out} =

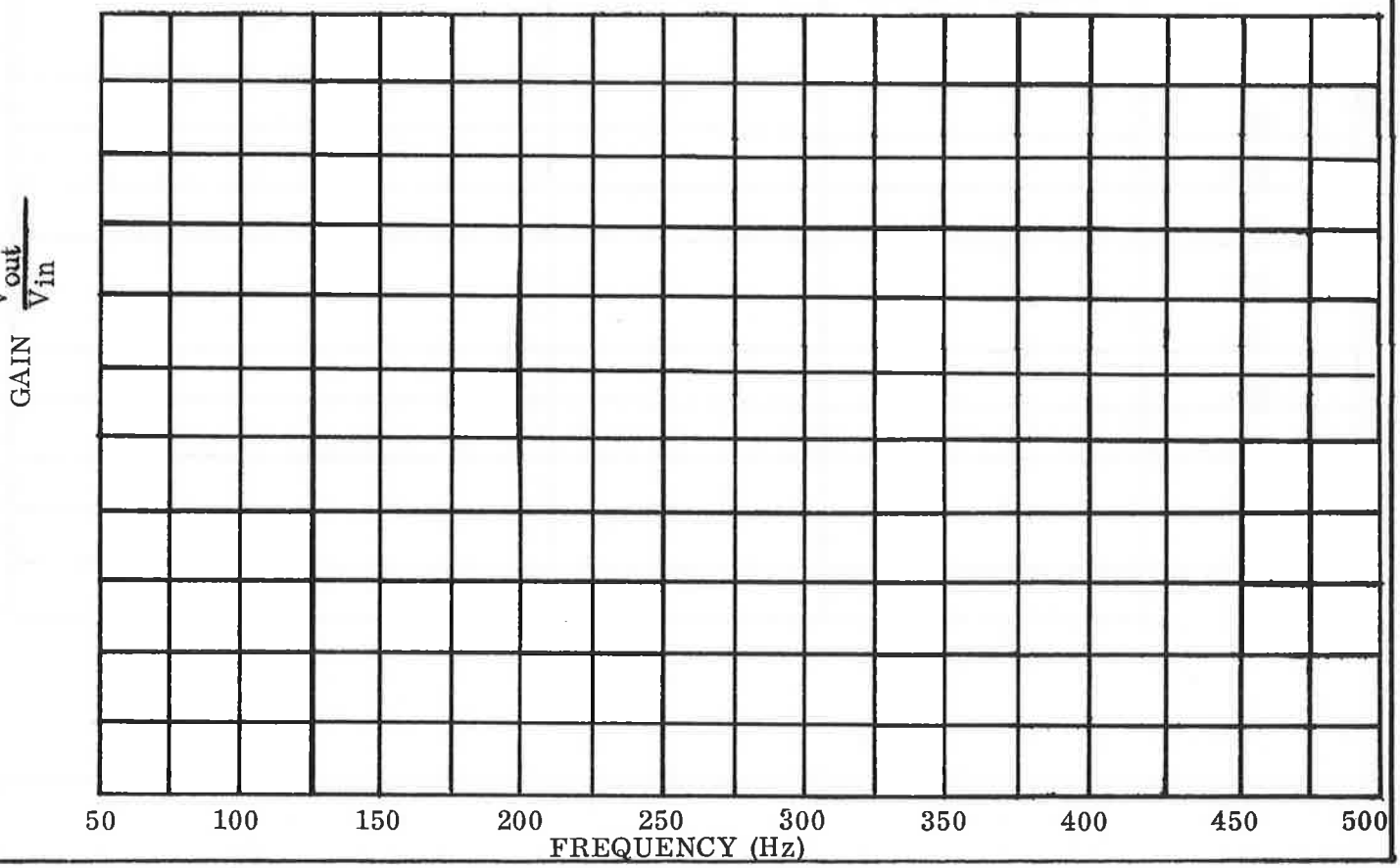
16. Adjust the Input Frequency to the values indicated in the table below. Make sure the Input Amplitude is set to the level of step 14 for each frequency. Record the V_{in} peak to peak and V_{out} peak to peak for each frequency.

freq. (Hz)	V_{in} p-p SWITCH A DOWN Set to level in Step 14	V_{out} p-p SWITCH A UP	GAIN = $\frac{V_{out}}{V_{in}}$
50			
100			
150			
200			
250			
300			
350			
400			
450			
500			

17. Take data for six additional frequencies centered around the Resonant frequency f_R. These six frequencies are described in the table below.

frequency	V_{in} p-p	V_{out} p-p	Normalized Output $GAIN = \frac{V_{out}}{V_{in}}$
f_R - 30Hz =			
f_R - 20Hz =			
f_R - 10Hz =			
f_R + 10Hz =			
f_R + 20Hz =			
f_R + 30Hz =			

Plot the data taken in step 15 and 16 on the graph below. Select a suitable vertical scale.



18. Calculate the half power point

half power = Peak Output x 0.707

half power = ( ) x 0.707 = _____

Draw a horizontal line at the half power point on the graph of step 17.

19. Record the two frequencies at which the curve in the graph of step 17 cross the half power points.

f high =

f low =

Calculate the Bandwidth of the Band-pass filter

Bandwidth = f high - f low = ( ) - ( ) =

B.W. =

QUESTIONS:

1. For the Band-pass filter response, does the filter have Gain greater than 1 at resonance?

2. Why is a Low Pass filter with a higher rolloff rate considered "better" for most applications than one with a lower rolloff? (Hint: Think of the reason you might use a Low Pass filter - such as a Hi-Fi Scratch Filter.)

Ed-Lab	HEARTBEAT MONITOR	EXP. NO. 26 Page No. 1

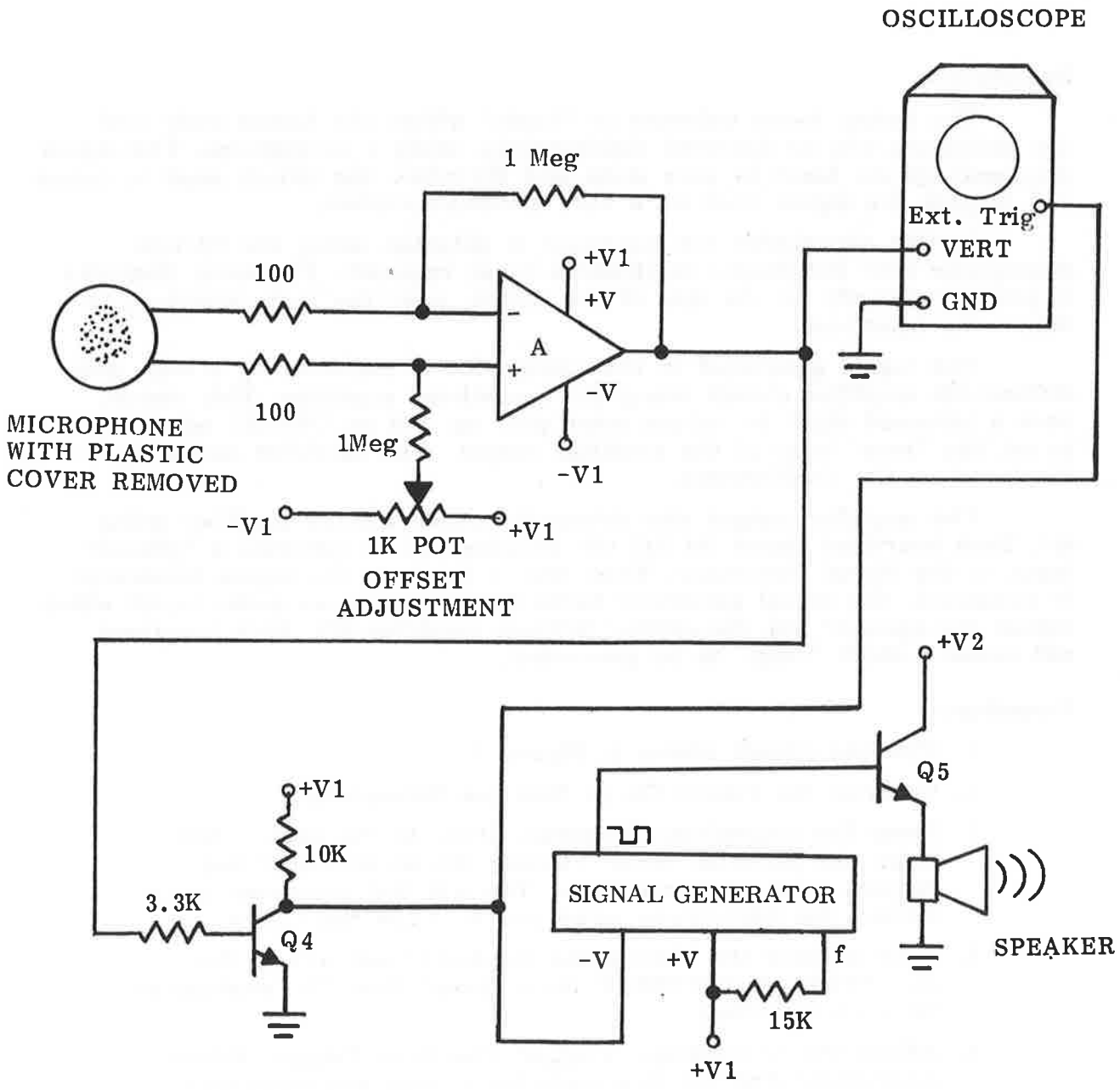


Figure 26-1 Heartbeat Monitor

Objective: To detect the human heartbeat and to monitor the heartbeat by means of an oscilloscope trace and an audio signal.

Description:

The human heart pulsates or "beats" within the human body and the pulsations can be detected electronically using a microphone. The signal produced by the heart is very weak and therefore the circuit used to detect and display the signal must be a very sensitive system.

In this experiment the heartbeat is detected using the Ed-Lab Microphone with the Plastic Mouthpiece cover removed. The metal diaphram is pressed directly on the side of the throat, near the large arteries, to detect the heartbeat.

The signal generated in the microphone is amplified by a high gain differential amplifier circuit using the operational amplifier. This circuit uses a balanced input to reduce noise pick up and an OFFSET adjustment to set the "zero" level of the amplifier output. The amplifier output is displayed on the Oscilloscope.

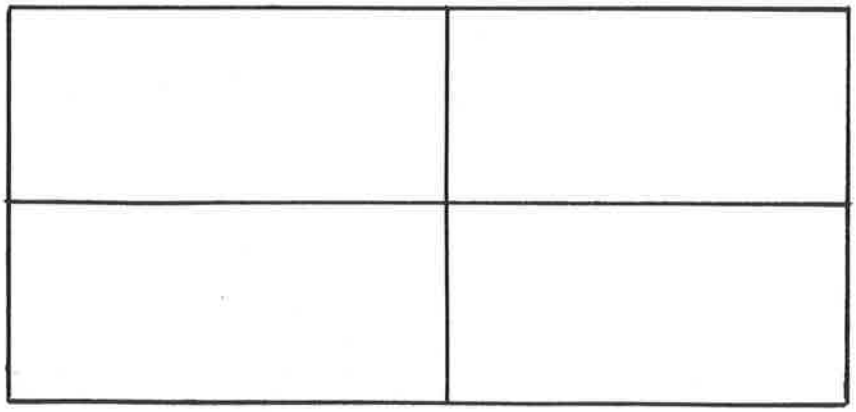
The amplifier output also drives a common emitter amplifier using Q4. Each heartbeat turns Q4 full ON (Saturation) to generate a "ground" input to the Signal Generator. When the -V input to the Signal Generator is grounded, the signal generator turns ON and emits an audio signal which drives the speaker via the emitter follower amplifier Q5. Each heartbeat will cause a short "peep" to be generated.

Procedure:

1. Wire the circuit shown in Figure 1.
2. Unscrew the Plastic Cover from the Microphone.
3. Press the Microphone Diaphram firmly to the neck - just below the jawbone. Note: Finding the correct spot may require some trial and error. You will feel your own pulse moving the microphone when you find the right spot.
4. While holding the microphone to your throat adjust the 1K OFFSET ADJUSTMENT for a "peep" from the loudspeaker for each heartbeat.
5. Adjust the Oscilloscope Trigger (Negative Trigger Pulse) Adjustment and the time scale for a clear waveform with each heartbeat.

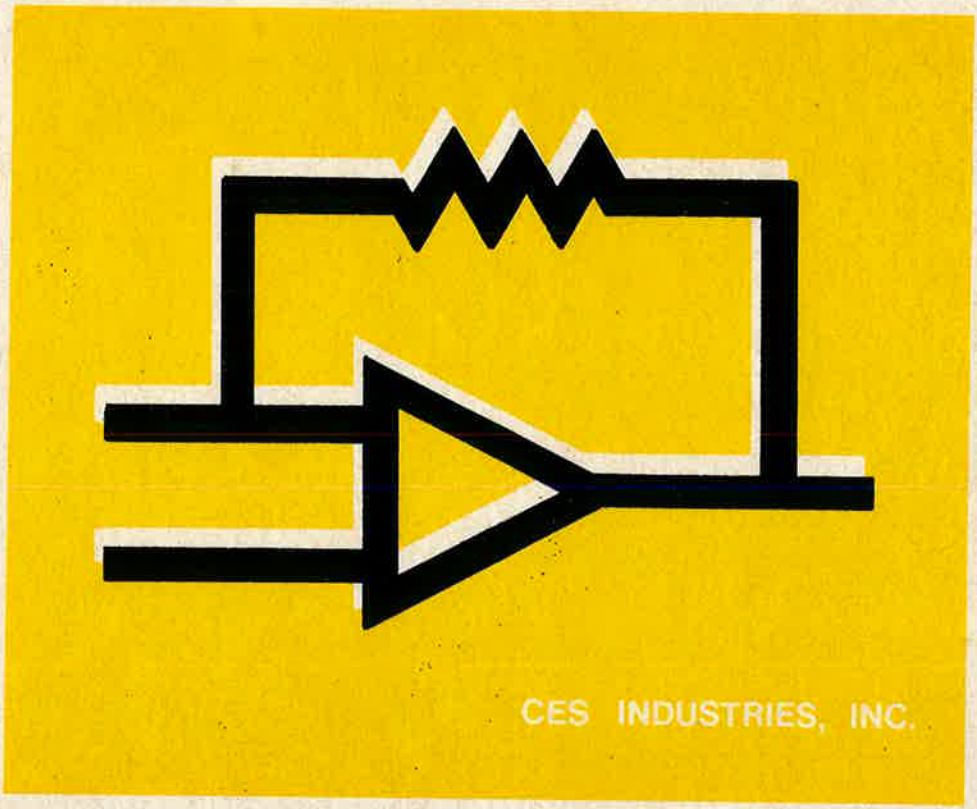
6. Sketch the Waveform observed for a typical heartbeat.

   HEARTBEAT WAVEFORM:



7. Count the number of times your heart beats each minute. Use a watch for the timing and count the audio "peeps" to mark the heartbeat.

   Pulse Rate: _____ Beats per Minute


CES INDUSTRIES, INC.